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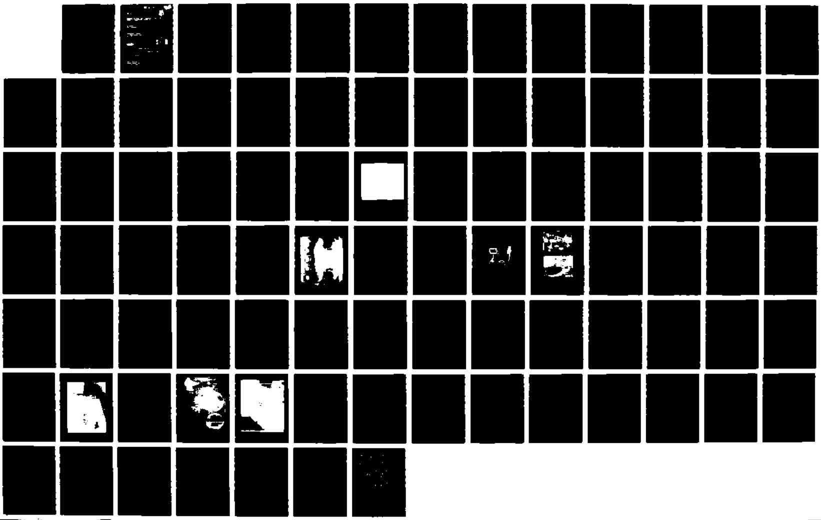

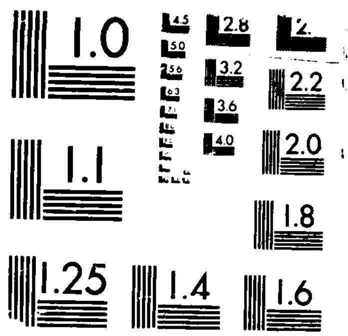


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# REVIEW OF PAST AND CURRENT TRIALS AND USES OF UNMANNED VEHICLES

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This report presents an analysis of unclassified information regarding the past and present trials of Unmanned Vehicles (UMV's). The effort reported herein included (1) a historical review of the man-machine interface (MMI) involving the control of unmanned vehicles, (2) an assessment of the problems and successes associated with different MMI designs, and (3) projection of trends and identification of technologies having the greatest potential for improving the MMI. The most significant historical MMI problems, solutions and historical lessons are provided in the body of the report.

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## FOREWORD

This research effort was conducted under the direction of the Deputy for Development Planning, Human Systems Division, Brooks Air Force Base. The contract monitor for this effort was Captain Gene Uhuad, HSD/XRX. The technical advisor was Dr Robert Mills of the Harry G. Armstrong Aerospace Medical Research Laboratory at Wright-Patterson Air Force Base.

While the direction provided facilitated the accomplishment of the assigned research, the views, opinions, and/or findings reported herein are solely those of Quest Research Corporation and should not be construed as an official U.S. Air Force position, policy or decision unless so designated by other documentation.

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## PREFACE

The requirements of this task were to (1) trace the history of the man-machine interface (MMI) involving the control of unmanned vehicles (UMV), (2) assess the problems and successes associated with different MMI designs, and (3) project trends and identify emerging technologies having the greatest potential for improving the MMI.

This report presents an analysis of unclassified information gathered through a literature review, correspondence with manufacturers, interviews with current and former members of the military, and extensive interviews/reviews via on-sight visits to three U.S. manufacturers.

There have been many UMV designs since the first powered, pilotless aircraft, the Kettering Bug, was developed in 1917. There is not a readily available data base to describe the MMI concepts for each of these designs. However, numerous UMVs incorporated the same MMI design, and this reduced the complexity of the task.

There are several reasons why there is so little data discussing the MMI compared to the wealth of data covering other aspects of UMVs. Most manufacturers prefer to publish data about the air vehicles, instead of the control stations, launch systems or recovery systems. Most public debate concerning UMVs deals with such issues as missions, payload versus vehicle costs (the payload can cost as much or more than the vehicle and its support equipment), and vehicle recovery. Exploration to develop more effective MMI designs has been taking place in Government and industry laboratories, but the results of these efforts do not draw the same level of publicity. Emerging technology in communication data links, video cameras/other optical devices, and automatic flight control/navigation equipment can have a significant impact on future MMI designs.

This report covers all material found in the open literature and in our discussions. The most significant historical MMI problems, solutions, and historical lessons are provided in the body of the report. However, this report does not cover everything of interest in UMV MMI. Other efforts are taking place, but their classification precludes their coverage here.

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# 1.0 INTRODUCTION

Unmanned vehicles (UMVs) have played a role in military operations since World War II. Each UMV requires some degree of human interaction from continuous flight control through supervision of operation. Depending upon the UMV design and mission, human interaction can occur at vehicle launch, during flight of the vehicle, and during vehicle recovery. The UMV operator interacts with the air vehicle through some type of control station.

The control station consists of the necessary equipment to send commands to the air vehicle and, in turn, receive status information from the vehicle. For those vehicles that have a real-time sensor like a television camera, the control station must also be able to transmit commands to the sensor, and receive data from the sensor. The interaction between the equipment and the operator occurs through the man-machine interface (MMI). The MMI could be as simple as a control box with a joystick and a few push-buttons, to a fully instrumented cockpit similar to cockpits found in manned aircraft. The UMV MMI design is driven by the air vehicle's mission, flight control systems, and payload.

The MMI has slowly evolved over time, its development being affected by the mission, available technology, and limited financial resources. The requirement for unmanned vehicles to perform the reconnaissance mission resulted in an MMI where there was no longer visual contact between the operator and the vehicle. Radio, television, radar, computerized flight controls, and advances in avionics and communications equipment are some of the technology areas that have impacted MMI design. Historically, unmanned vehicle research would be funded only when budgets were not tight, and many times, UMV research resulted in makeshift equipment designed to meet the immediate needs of the users. The role these factors played in the development of MMI designs will become clearer as this report traces the historical development of MMI designs, identifies their strengths and weaknesses, and identifies the future technologies most likely to improve MMI design.

## 1.1 Structure of the Report

The emphasis of this report is on MMI issues and their resolution. This section defines the basic terminology that will be

used in the rest of the report, introduces several key concepts, and presents a discussion of the study methodology. Section 2 describes the history of UMV control stations, sets the context for the remainder of the report, and identifies potential MMI issues. The MMI issues, their impact on the UMV operator, and the historical efforts to resolve them form Section 3. Section 4 addresses current research efforts that attempt to better understand MMI issues, and the way these research efforts can affect the MMI. The key technology areas that can have the greatest impact on the MMI are summarized and prioritized in Section 5.

## 1.2 Terminology Defined

Unmanned vehicles, remotely piloted vehicles (RPV), drones, and cruise missiles are all powered pilotless aircraft. RPVs are vehicles which are flown in a closed-loop fashion with an operator in the loop. The earliest developments consisted of radio control for full sized aircraft and for small or model aircraft. The control stations for the full sized aircraft were similar to cockpits found in manned aircraft, and these UMVs required a pilot operator to actively fly the vehicle. The smaller vehicles were being flown by non-pilot operators and the control station consisted of a box with a joystick and a single push-button switch. Both RPV types were used as targets for antiaircraft artillery batteries.

Drones and cruise missiles, which evolved from early RPV research, operate under programmed control except at times of recovery. Drones and cruise missiles have the necessary internal navigation equipment and flight control systems to allow the operator to launch and forget. The operator need only program the vehicle prior to launch. Drones are recoverable, while cruise missiles, at least operationally, are not recoverable.

Powered pilotless vehicles can be divided into four groups on the basis of the required interaction between the operator and the vehicle. Group 1 consists of UMVs that require an operator, because preprogramming is not possible. Group 2 UMVs are preprogrammable, but manual control during the mission is possible. Control of Group 3 UMVs in flight is only indirectly possible; the operator can program a change in flight

path with the automated flight control computer taking the appropriate action. The last group, Group 4, consists of drones, cruise missiles, and other preprogrammed UMVs. No in-flight control is possible. Operator interaction is only possible during launch and recovery. For this report, the phrase UMV applies to all vehicles in Groups 1 through 3.

Regardless of size, UMV systems have three or four subsystems depending upon whether the vehicle is recoverable or not. The UMV system consists of: The vehicle, ground and/or airborne control stations, launching equipment, and for those that require it, retrieving equipment.

There is a MMI between the operator and the control station, the launch equipment, and the retrieval equipment. This report concentrates on the MMI between the operator and the airborne/ground control stations. Launch and retrieval of the vehicle is considered only in terms of the impact on the MMI between the operator and the control station.

## 1.3 Key Concepts

### 1.3.1 UMV Missions

The mission to be performed is the major driver to the air vehicle, control station, and MMI design. The earliest missions for UMVs were as targets for gunners. Control stations were relatively simple because the UMV was always in sight of the operator. The operator used visual cues to obtain flight status data. Fundamental changes in MMI design occurred when advances in technology permitted the vehicle to carry a payload beyond visual range and provide the operator with real-time data from the payload.

Some of the missions UMVs can perform are:

- Target
- Photo reconnaissance
- Video reconnaissance
- Pre- and post-attack assessment
- Weather reconnaissance
- Artillery spotting
- Radiation, chemical or, biological contamination identification

- Communications relay
- Psychological warfare
- Electronic countermeasures
- Weapons delivery
- Kamikaze weapon
- Electronic intelligence

The mission of the UMV determines the tracking requirements, and the in-flight communications required between the vehicle and the operator. Tracking requirements can be satisfied by visual, radar, and/or television control. Communications requirements involve both vehicle-to-operator (flight status, sensor data) and operator-to-vehicle (reprogramming, flight control) communications. Subject to the constraints of available technology, it is the interrelationships between the UMV mission, the tracking requirements, and the communication requirements that establish the nature of the MMI.

Control stations for UMVs that fly beyond visual range, but lack a real-time sensor data link, are more complex than the control stations used for the visually tracked UMVs. However, there is usually less interaction between the human operator and these UMVs because of the automatic flight control equipment incorporated into these vehicles. Control stations associated with UMVs that require a real-time data link are the most complex. The incorporation of real-time communications from the sensor results in a minimum of additional displays and command control hardware, and can require the incorporation of an additional operator.

### 1.3.2 Vehicle Types

Almost all unmanned air vehicles can be classified according to their size into three classes. Today, military services seem to prefer the mini UMV or those weighing approximately 600 pounds or less. These systems are based on steadily improving model airplane technology and are the results of engineering efforts to reduce size, weight, and power requirements of engines and avionics. These systems have proven themselves in combat, most recently by the Israelis in their attack on the Syrian positions in Lebanon. Medium sized vehicles are larger and

faster than the smaller vehicles. The reconnaissance UMVs of two decades ago would today be classified as medium size. With the advances in technology, the missions that once required a medium size vehicle can now be performed with the smaller UMVs. The High Altitude Long Endurance (HALE) UMVs and similar vehicles are in the third class. These vehicles are considerably larger, weighing between 5,000 and 15,000 pounds. These systems are designed to carry sensors at altitudes between 50,000 and 80,000 feet and remain aloft for days.

### 1.3.3 Technology

Technology has had a significant impact on the design of the UMV MMI. Automated flight control computers gave the vehicle the ability to fly beyond visual range. At first, the operator could launch the vehicle, fly it beyond visual, but not radio range, and send the necessary commands for the vehicle to make a 180 degree turn. Then the vehicle would automatically fly back into visual sight where it was "reacquired" by the operator.

Radar tracking and the incorporation of an X-Y plotter for navigating the vehicle beyond visual range fundamentally altered the MMI. This change allowed the vehicle to perform reconnaissance and other intelligence gathering missions in areas where it was unsafe for manned aircraft and far beyond the position of the operator. However, as distance and flight duration increased, more flight status information was required; therefore, more controls and displays were added to the control stations.

The incorporation of the video cameras and other optical devices (e.g. IR imaging systems) to transmit pictures in real time also had a significant impact on MMI design. Usually, it meant the addition of another operator to the crew controlling the UMV. Many MMI designs today call for three operators: The mission commander, the vehicle operator, and the payload operator. The Israeli concept is to have a two person crew consisting of the UMV operator and the target identifier.

While UMV control stations were evolving from visual, to radar, to video feedback, another trend was evident. On the one hand,

control stations were becoming more complex as additional data from the vehicle was required. The incorporation of special payloads, resulted in several UMV designs requiring multiple operators: a mission commander, a vehicle operator, and a payload operator. On the other hand, design engineers developed improved methods for automatic control. Some of the current UMVs can fly a preprogrammed flight plan, engage in evasive maneuvers if attacked, and still have the navigational accuracy to complete the mission.

### 1.3.4 Other Factors

There are numerous unresolved questions relating to interfacing operators with UMVs. These questions are related to the uncertainties about the types and nature of the airborne vehicles, their instrumentation, their numbers, and the specialties and qualifications of the operator.

Should the UMV operator be a rated pilot accustomed to a three dimensional view of the target, or an air traffic controller or weapon system operator (WSO), both of whom are accustomed to working in the two-dimensional environment which typifies UMV ground control stations? Should ground control of multiple UMVs be conducted from a single control station or from a number of coordinating stations with one operator passing off control of the vehicle to another operator during various stages of the mission? How much control and decision making equipment will be incorporated into the vehicle? The more the vehicle is automated, the less there is a need for an in-flight operator to do anything more than monitor the status of the vehicle. What role is the operator to play in launch and recovery? Will the operator need to take control of the UMV upon launch? Will the operator need to bring the UMV in for a "normal landing", or does the system employ a parachute recovery system? Does the UMV have to occupy the same airspace as manned aircraft? The more coordination there must be between the manned aircraft and the UMV operator, the more complex the MMI will become. With long endurance machines that can stay up for days, how much monitoring is required of the operator? Feedback for exceptions could be provided, but the problem may be boredom.

## 1.4 Study Methodology

This study effort was divided into three separate phases. The first phase required the identification of all known uses of UMVs, and an analysis to determine the extent of the requirement for an operator. The first phase constituted an in-depth literature search, the identification of manufacturers, and the creation of a data base using a personal computer and dBASE III software. Manufacturers were contacted and asked to submit information relative to the MMI associated with their UMVs for incorporation into the data base. Over 340 different uses and trials of UMVs worldwide were identified. Finally, each UMV was classified into one of the four categories described in Paragraph 1.2.

During Phase II, the MMI designs associated with the relevant UMVs were analyzed in greater detail. The historical development, the underlying technology, and the strengths and weaknesses of these designs were studied. For discussion purposes, MMI designs were divided between those limited to visual tracking, those that use visual or radar tracking, but lack a video camera or video downlink, and finally, those with radar tracking and/or a television camera requiring a video downlink. This analysis identified the underlying trends in their development. As part of this effort, technical meetings were held with several design engineers and operators. A performance comparison analysis was also conducted on the various MMI designs. The last step in Phase II was to identify the advantages and limitations associated with having an operator in the control loop, the MMI itself, and the air vehicle.

Phase III called for the identification of those technologies that will impact the man-in-the-loop, the MMI, and the air vehicle. The analysis identified the technological issues being explored in the laboratories today. On the basis of this analysis, it was possible to project the impact the technology will have on the MMI once it transitions to the developing community.

## 2.0 HISTORICAL DEVELOPMENT OF UNMANNED VEHICLES

This section explores the development of UMV control systems from a historical perspective. Its purpose is to provide a general background of what has occurred in order to identify potential MMI issues. As UMV development has driven MMI design, this section follows the hardware development to identify MMI issues. Issues are identified in **boldface** type when they are first mentioned, and the issues are summarized at the end of this section. Although MMI components were to be emphasized from a historical perspective, only minimal details were found in the data. Thus little historical MMI data is available, a clear illustration of the lower priority given this area in the past. The narrative is divided into four time periods. UMVs developed up to World War II are discussed in Paragraph 2.1. UMVs developed between World War II and 1960 are discussed in Paragraph 2.2. The Vietnam War years, 1960 to 1972, were the years that Teledyne Ryan had a virtual monopoly on U.S. UMV business, and the control process used for these reconnaissance UMVs is described in Paragraph 2.3. Paragraph 2.4 discusses the modern era. Each of these paragraphs provide descriptions of the types of control systems, the underlying technological limitations, and the evolutionary changes that occurred. This section concludes in Paragraph 2.5 with a summary of MMI issues.

### 2.1 1917 to World War II, The Early Years

### 2.1.1 The Beginnings

UMVs can trace their beginning back to 1917 and the Kettering Aerial Torpedo, otherwise known as the "Kettering Bug". Developed by Charles Kettering, the Bug was a biplane drone with a reciprocating engine. The vehicle carried a payload of 180 pounds of explosives, flew at 55 mph, and had a range of 40 miles. The Bug would be launched with pre-set flight controls. At the target, the wings were released, and the fuselage would fall as a gravity bomb. The Bug was not a true RPV, because there was no method available for remote control of the vehicle once it was in flight. Remote control required the development of radio technology in the 1920s; before a vehicle controllable in flight could be developed. (1,86)*

* Numbers in parentheses refer to the source and page number. A complete list of references is provided at the end of this report.

The first radio controlled aircraft was a Curtiss Robin monoplane. First flown in 1928, the Curtiss Robin demonstrated the ability of a radio controlled, bomb carrying aircraft. The program continued on minimum funding until 1932 when it ended because of a lack of funds. It would be another four years before the U.S. Navy would initiate the development of a radio controlled target. The U.S. Army Air Corps would wait an additional two years. (1,86)

### 2.1.2 The First Navy Target UMV

As a young officer, Rear Admiral Delmar S. Fahrney (ret) was tasked in the summer of 1936 to learn all he could about the control of land, sea, and air vehicles, and to develop a program that would provide the Navy's antiaircraft gunners with a realistic aerial target within three to five years. At the Naval Aircraft Factory in Philadelphia, Fahrney and his team modified two Stearman Hammond JH-1 planes. They installed special radio equipment that had been developed at the Naval Research Laboratory. (2,54-55)

By 1937, the Navy was conducting flight tests at Cape May Coast Guard Air Station. The aircraft, now known as the N2C-2 was controlled from two control stations. The first station was located on a cart placed near the runway. The operator manipulated stick, rudder, and throttle controls similar to those on an airplane. The operator's movements were translated into radio signals and transmitted to receivers on the aircraft. The same control station equipment was built into the control airplane, a TG-2. The ground operator would control the vehicle from takeoff to an altitude of 200 feet. At that point, control of the vehicle would be transferred to the airborne operator orbiting overhead in the TG-2. After aerial maneuvers, the airborne operator would set up the approach, but the actual landing would be conducted by the ground operator. (2,55)

The first flight test of the N2C-2 without a safety pilot was made in November, 1937. The takeoff, air maneuvers, and landing approach were perfect. However, the landing was rough; the aircraft hit hard on the front wheel, which collapsed. The other wheels of the tricycle gear folded and the propeller was bent. Yet, the damage was repairable. Just before Christmas, 1937, a flight was completely

successful. This was the first time a full size aircraft had been totally under radio control. Within a year, the Navy was testing its new target against the gunners on board the aircraft carrier Ranger and the Utah. (2,55)

Two U.S. Army Air Corps officers from Wright Field, Captain George Holloman and Lieutenant Rudolph Fink witnessed Navy testing of the target drones in the winter of 1939. They witnessed ground control testing when the targets were used by the USS Idaho and they flew in the control aircraft when the targets were used against the USS Patterson. They recommended the Air Corp initiate radio controlled target programs. Major General Arnold requested the Navy provide a UMV, a control plane, and a ground cart. The equipment was delivered in the summer of 1939. (2,56)

Judging by today's standards, Fahrney's efforts were crude. Yet he and his team identified many of the problems that UMV designers and users are stilling working on. First of all, the JH-1 did not have automatic pilots or gyro instruments for course corrections. The operator was forced to fly the vehicle as if seated in the cockpit. The ground operator experienced the problem of reversal. When the aircraft was approaching the runway for landing and the operator faced the aircraft, the right wing was on his left. The ground operator had to learn to "reverse control" the vehicle upon final approach. The problems identified with landing the vehicle began what today is still one of the major problems with UMVs; namely, recovery. In addition, the operators had to learn how to determine the aircraft's attitude and bank with only visual cues. Instrumentation was very limited.

### 2.1.3 Mini UMV Development

While some efforts were being conducted on radio controlled full-size aircraft, others were trying to interest the services in smaller aircraft that could be used as free flying aerial targets. From the late 1930s through 1959, the primary mission of UMVs was as targets, and almost all development activity was dedicated to working out the basics of remote control.

In 1935, Reginald Denny demonstrated a radio-controlled airplane for the U.S. Army at Fort McArthur, California. His vehicle

was a high wing monoplane constructed out of balsa and plywood. The aircraft had a 9-foot wingspan and maximum speed was only about 50 mph. Control reaction was not adequate and during the demonstration, the UMV crashed. The control station consisted of a 73 megacycle transmitter that could be modulated to any one of five tones. Each tone represented a single rate command to the UMV. The control box resembled a telephone dial and the operator was required to wear headphones to hear the tones being transmitted to the vehicle. Four tones could command Up, Down, Left, and Right. The fifth tone indicated "normal flight" or no other tones present. (3,11)

Denny went on to modify and improve his small targets. The Army purchased 53 vehicles of his fourth design. The company formed to build these units was the Radioplane Company. (Mr. Whitley Collins, the first President of Radioplane went on to become the President of Northrop after Northrop and Radioplane merged in the 1950s.) (3,11)

2.1.4 Mini UMV Production Targets

Radioplane began developing, producing and selling a variety of targets for training. These early systems were relatively small. They were about 104 inches long, their wingspan was about 146 inches, and they weighed approximately 100 pounds. These early UMVs designated the OQ-1, OQ-2, OQ-3, and OQ-14 were used for target practice prior to and during World War II. (3,11-27)

The control systems were essentially the same for all these vehicles. The UMV contained a 12 inch antenna, a receiver, battery, cables, and servo actuators. The receiver had a tuned amplifier stage, and its audio output was fed to a series of five band-pass filters. These five filters were tuned to 300, 650, 955, 1390, and 3000 Hertz respectively, and activated relays which caused servo actuation or parachute door release. The servo unit, actuated by electrical energy from the receiver relay circuits, provided the mechanical action needed to control the rudder and elevator. The servo unit consisted of two 6-volt motors with reversible fields. These motors operated gear trains which provided the required mechanical advantage. (3,17)

The ground control station consisted of a radio transmitter and modulator, a Dynamotor, a control box, an antenna, cables, and a power

unit. The transmitter was crystal controlled and factory pre-tuned to 73 MHz. A control stick actuated control box replaced the earlier telephone dial design. Movement of the joystick would cause the transmitter to be amplitude modulated by any one of four audio tones, representing the commands Up, Down, Left, and Right. The fifth tone, the parachute command was the original "normal mode" tone. An audio signal was always transmitted to the target. The parachute command was a continuous signal that could be interrupted by a joystick command. Because the vehicle still received a signal, the parachute would not deploy. Use of an interrupt switch (push-button on the control box) or loss of signal would result in parachute deployment after a one second delay from receipt of signal. Audio frequencies used to control the target are provided below.

| COMMAND | FREQUENCY |
|---|---|
| Right | 300 Hz |
| Left | 650 Hz |
| Parachute | 955 Hz |
| Up | 1390 Hz |
| Down | 3000 Hz |

The transmitter received its power from the Dynamotor unit which in turn was powered by a gasoline generator. (3,17-18)

The Radioplane targets were limited to flight within line of sight of the operator. There was considerable variability in the distance these RPVs could be flown because of the eyesight of the operators. To aid visual sighting, the top of the target's wings were painted white, while the bottoms were painted bright red. The operator's visibility ranged from 1 1/2 to 5 miles with about 3 miles being the average. Cloud cover was usually not a problem because these vehicles were designed for low level flight. (4)

The operator held the small control box in the palm of his hand while manipulating the joystick with the other hand. These commands were simple rate commands. That is, a left command would result in increasing bank and eventually roll the vehicle unless a right command was provided to restore the ailerons to neutral. Such improvements as position control or proportional control were to come later. (4)

## 2.2 World War II to 1960, Experimentation

During this period, three major technology areas were explored to determine their application to UMV systems. These technologies were automated flight controls, radar tracking/control, and television/video transmission.

### 2.2.1 Automated Flight Controls

During the 1950s, Northrop was improving their target systems. They developed a vehicle that contained the E-16 control gyro. This device automatically restored the flight control surfaces to neutral once the vehicle had assumed the desired attitude. The control system was revised to take advantage of the inherent position command capability. The control box no longer provided a rate command that had to be countermanded. The operator now knew that each click of the joystick resulted in a specified amount of bank or pitch change. With this known capability, the operator could now allow the UMV to fly beyond visual range, because directing and/or controlling a UMV through a 180 degree turn was relatively easy. Northrop also experimented with barometric and radar altimeters, which eventually resulted in an altitude hold capability. The altitude hold capability simplified the flying of the target, and was the first application of an autopilot connected to ailerons and elevator servos.

The incorporation of jet engines provided UMVs with higher altitude capabilities and much faster speeds. By the mid 1950s, UMVs could fly at supersonic speeds. At low altitudes, the decision time available to the operator was significantly reduced. With the increased power, it was possible to fly the vehicles at altitudes and speeds well beyond visual limits.

### 2.2.2 Radar Tracking and Control

Another development during World War II was radar tracking control. UMV design engineers attached a radar transmitter to the vehicle and the signal return was translated into the movement of two pens on an X-Y plotter. One pen would mark the range and direction, while the second pen marked altitude. (5,748) With some of the new flight controls available, the operator was now able to fly the vehicle beyond visual range. The plotter was used to determine position of the

vehicle. With the plotter, it was also possible to plot the route being flown by the vehicle directly onto maps of the target areas.

Although the incorporation of the X-Y plotter allowed UMV flights beyond visual range, additional training was now required. Operators had to learn how to visualize the position and attitude of the vehicle without the benefit of visual cues. At this time, instrumentation was still limited.

2.2.3 Video Control

In February of 1941, the Navy had signed a contract with RCA for the development of a small TV transmitter to be carried in a missile and a small receiver to be installed in a control plane. Once testing was satisfactory completed, the Navy went on to develop an "assault drone". The first concept consisted of a radio controlled torpedo bomber which would fly at a set altitude using a radio altimeter, and would be visually guided to the torpedo release point by remote control. (2,56)

In 1942, the Navy tested their first torpedo attack. The air operator, using radio control, flew the vehicle. When the UMV was approximately 8 miles from the target, the operator picked up the target on his monitors even though he was twenty miles away at the time. When the vehicle appeared to be 300 yards from the target, a radio signal command released the torpedo. (2,56)

The first Kamikaze mission was conducted 10 days later. The operator picked up the moving target when the vehicle was 4 miles away from the target. He then flew the drone into the target while flying in the control plane, 30 miles away. (2,56-57)

Although there were experiments involving radar and television control systems during this period, visual control was still the primary method. The Air Force demonstrated the ability to fly an unmanned B-17 bomber from Hawaii to California, but the control ship remained in sight of the vehicle. In spite of the limitations in the control technology of this time period, most of the technology leading to the automated capabilities of today's UMV can trace its beginnings back to this period. (5,750-751)

## 2.3 1959 to 1972, The Vietnam War Years

### 2.3.1 Reconnaissance Missions

By late 1959, overflights of the Soviet Union using high altitude U-2 reconnaissance spy planes had been going on for three and a half years. There was concern at high levels in the Air Force about the potential for a U-2 coming down in enemy territory killing the pilot, or worse, with the pilot being captured. Several individuals within industry and government started work on converting target drones to photographic reconnaissance vehicles. Within 8 months, Francis Gary Powers was shot down over Russia. Within 10 months the U.S. Air Force awarded a contract to Teledyne Ryan to modify its target drones into an unmanned, remotely controlled, photo-reconnaissance vehicle. (1,8)

"Red Wagon" was the code name for both the flight demonstration and the Ryan Model 136 proposed to fully develop the drone reconnaissance potential. The modified Firebee target drone that eventually became the production version, the BQM-34, had larger wings of increased area, a jet engine with added thrust for higher altitudes, and added fuselage length for extra fuel capacity. Special controls and navigation systems, electronic programmers, precision altimeters, camera systems, and other sophisticated hardware resulted in a vehicle that could handle a variety of missions.

The UMV business really began with Ryan's BQM-34A. During the Vietnam War years, this target drone evolved into a family of special purpose aircraft. BQM-34's and their derivatives were used for day and night photo reconnaissance, electronic intelligence, electronic support, and propaganda missions. From 1964 through April 1975 these vehicles were regularly flown on reconnaissance missions.

The flight crew was composed of pilot, co-pilot and flight engineer, and a launch control operator (LCO). Once the vehicle was launched from the DC-130 aircraft, the job of the LCO was completed. There was also one or more airborne remote control operators (ARCO) on board the aircraft. They faced a display panel which provided them with information on vehicle location, and instruments presenting attitude information. Although the reconnaissance mission was normally automatic, the ARCO or ground remote control officer (GRCO) could command the

vehicle through the microwave command guidance system (MCGS) associated with the airborne or ground stations. Prior to the introduction of the MCGS in 1966, operators were relying on older beacon/radio control technology which was subject to interference from other radio sources.

At launch, it was important for the DC-130 to be at an exact predetermined point flying on a precise heading, for this information was used as the initial input in the navigation calculations for the vehicle's programmed mission. Any mistake at this point would translate into navigational errors during the mission. After launch, the ARCO would monitor the displays. When the vehicle began its journey home, the ARCO would pick up the vehicle as a blip on the radar scope. The ARCO would, if necessary, fly the vehicle to the recovery point where control would be transferred to the GRCO for recovery. Transmission delays were negligible. Furthermore, there was little concern over jamming of the data link. Most of the time, the MCGS was "on" and the vehicle was beaconing.

In the early days, recovery consisted of a parachute descent to the recovery area, be it land or water. Loss of signal or a command from the control station would cause the vehicle to deploy a parachute and descend to the ground. Once the vehicle was on the ground, it was retrieved. Vehicles landing in the water could be retrieved and would undergo salt water decontaminated if necessary. Many times however, the vehicle sustained damage because it hit the ground hard, the parachute failed to deploy, or the parachute release did not work and the UMV was dragged across open ground. To avoid many of the problems with the parachute recovery system, Teledyne Ryan developed the mid-air retrieval system (MARS), the recovery system that got the most use during this period. Once in the recovery area, the UMV would be commanded to release the parachute. The parachute system consisted of a drogue chute that would deploy first, followed by the main chute. The retrieval crew used a specially modified helicopter to snatch the lines of the drogue parachute and reel the drone into a transport position, whereupon the helicopter would return to base with the vehicle suspended beneath the helicopter.

One of the lessons from this effort was that if recovery of

the payload was required, MARS was vehicle and manpower intensive and only worked about 90% of the time, but it was better than letting the UMV descend all the way to the ground with only a parachute to break the fall, and no clear indication of exactly where the vehicle would touch down.

### 2.3.2 Other Ryan Initiatives

During this time, Teledyne Ryan personnel were working on a radar altimeter that would measure the height above the ocean and provide an electronic input into the control system to maintain a constant attitude. It was their radar altimeter low altitude control system which provided real time altitude readouts on the operator's console. They demonstrated the ability to control a vehicle 50 feet off the deck at 500 miles an hour.

Combat Dawn was a high altitude (50,000 ft) long term (4 hour) duration mission design to collect and relay to a ground site electronic emissions of particular interest.

### 2.3.3 Navy Television Guidance Experiments

In 1966, the Navy had requirements for an automatic drone-control system able to handle two QF9Js or BQM-34As in formation. A small radar was used as the formation positioning sensor. It required up- and downlinks, and all data was processed by computers on the ground. Figure 2-1 shows this closed loop system. In 1968, the QF9J used in the AFDC program was further modified to provide an all-attitude capability. It incorporated for the first time a forward-looking fixed mounted TV camera. The camera provided the remote pilot with takeoff, landing, and limited all-attitude capabilities. The camera also allowed the entire mission to be conducted by one operator. Also, in 1968, a BQM-34A was outfitted with a TV camera and a proportional-control system to demonstrate low altitude flight and high-g maneuvering. Tests successfully demonstrated low altitude flight to 150 ft AGL over the desert.

The QF-86H (F-6), a Navy target-aircraft modification of the 1970s, was a true RPV. The operator, stationed in an F-86H cockpit trainer (F-7), remotely operated the aircraft from takeoff until it returned to a stop on the runway. The QF-86H had no autopilot; the remote operator had to fly the aircraft throughout the mission. (6,59)

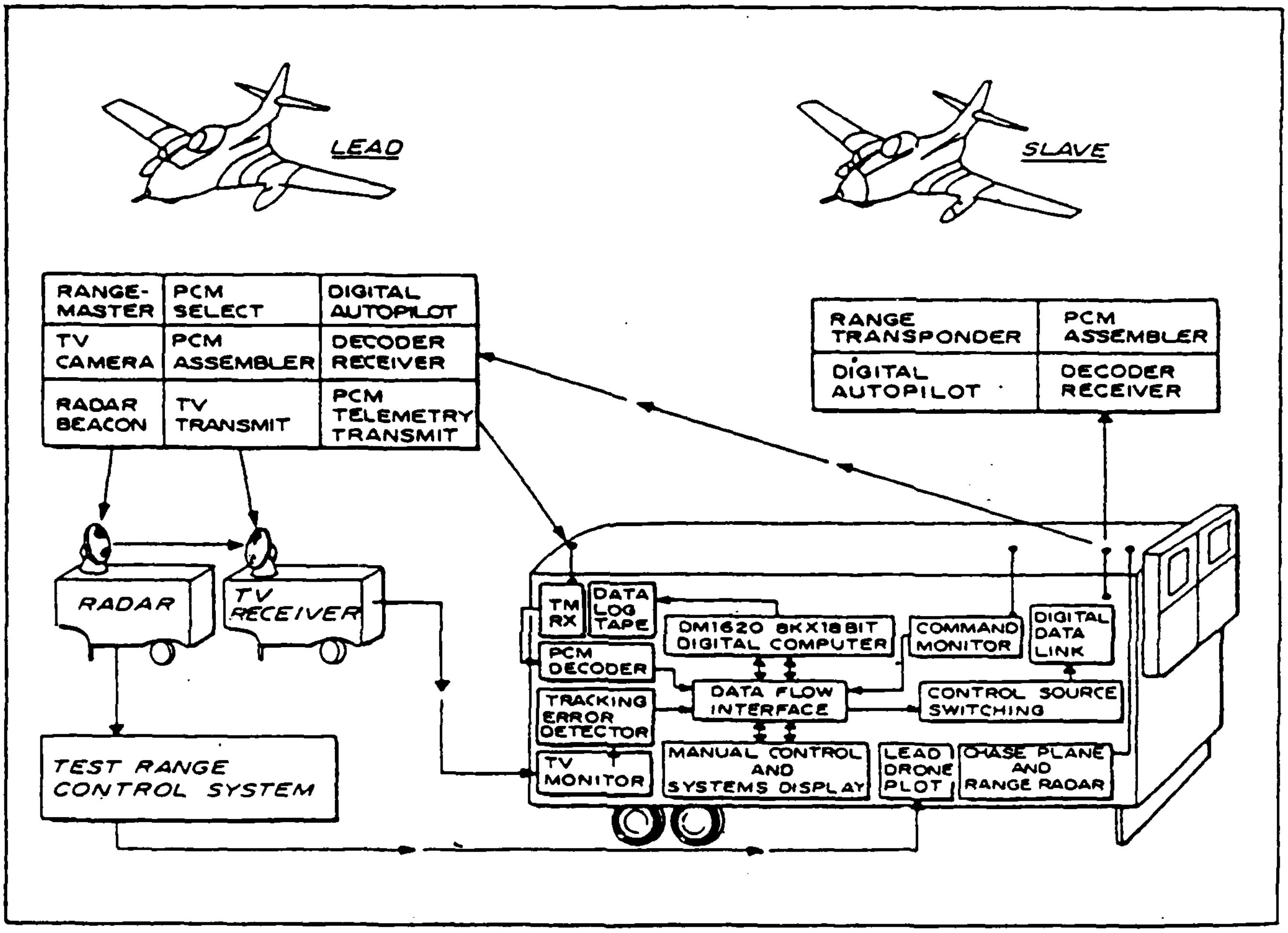



FIGURE 2-1 AUTOMATIC DRONE CONTROL SYSEM FOR QF9Js OR BQM-34As

### 2.3.4 Other Experiments

An Army experiment in the late 1960s at Miramar Naval Air Station, demonstrated that fairly simple controls were adequate during the flight, but the terminal phase required proportional 3 axis control. (7)

There were other experiments being conducted to improve the navigation accuracy of UMVs. The earliest navigation systems were little more than dead reckoning devices. With the incorporation of the LORAN navigation system, greater navigational accuracies were obtained.

## 2.4 1973 to Today, The Recent Years

After the Vietnam War, considerable developmental activity on UMVs took place, but very few systems made it into production for operational use. Even today, there are no systems in large scale production. This subsection is further divided into discussion of Government investigation of MMI issues, industry investigation of MMI issues, and some of the operational systems which resulted from these efforts.

### 2.4.1 Government Efforts

The Government efforts have tended to scope development to solve specific issues. The Government explored interservice use of UMVs and multi-country development of other UMVs such as Pave-Tiger. One of the issues dealing with video reception is the frame rate requirement. Such questions as whether the operator can work with slower frame rates, or delayed frame rates have been explored. In studies performed years ago, it was determined that slow frame rates tended to disorient the operator. (7)

- Flight Dynamics Laboratory. To explore these MMI issues, the Air Force instituted the FDL-23 testbed program in January 1972 at the Flight Dynamics Laboratory at Wright-Patterson AFB. The remote console for the FDL-23 system incorporated a large video screen providing a real-time display transmitted from a Cohu 945-line television camera located in the nose of the vehicle. The camera was equipped with a 10:1 remotely operated zoom lens that gave a maximum field of view of 53 degrees. Angle of incidence of the camera was also adjustable in flight from -10 degrees to +5 degrees. This capability enabled test engineers to adjust camera angle to accommodate changes in aircraft trim. Other

video presentations permitted display of the map from the radar plotter and a telescopic television system slaved to the tracking radar ground antenna.

**The operator's displays on the console included an attitude director indicator (ADI), vertical tape type airspeed/Mach and altitude/vertical speed displays. This situation showed the increasing use of standard flight instruments, and reflected a trend away from earlier experimental consoles vaguely reminiscent of industrial process control systems. The console provided a three axis side arm control stick at the right and a speed control at the pilot's left.** (8,65)

A similar control station was installed at Edwards Air Force Base. The control system operated through a Vega Precisions Laboratories data link system to actuate the three-axis proportional control system. The Vega C-band uplink could transmit to the vehicle by means of a four-pulse code which was transmitted slightly ahead of the main pulse from the FPS-16 tracking radar. Data from the vehicle was encoded and returned to the control station via the radar transponder reply pulse and then demodulated. Supplementing the three proportional control uplink channels were 34 on/off type uplink commands. Downlink capabilities included 26 proportional signals and 24 discrete signals. In spite of this capability, the system did not incorporate the necessary hardware to implement a microwave landing system capability. This additional capability would have added to the complexity of the ground station design and the MMI design. The on-board TV sensor could be zoomed and tilted remotely. The Flight Dynamics Laboratory explored the concept of using gimbaled sensor optics in its consideration of the value of open loop tracking. One technique used for closed loop tracking was to incorporate the equivalent of a missile seeker. The operator "flew" the seeker, and the seeker flew the vehicle. (8,65)

• <u>Crew Station Design Facility</u>. At the same time the Flight Dynamics Laboratory was exploring the merits of the FDL-23 testbed, the Crew Station Design Facility at Wright-Patterson was experimenting with its Dial-a-Drone control station. The system was built as part of a facility designed to simulate most any drone in the inventory at that time. Like the FDL-23, Dial-a-Drone also reflected a

trend toward actual aircraft flight instruments, including a panel incorporating attitude director indicator (ADI) and horizontal situation indicator (HSI), along with a vertical tape speed/Mach instrument, and a vertical altimeter. In addition, the panel incorporated an accelerometer and angle-of-attack indicating these instruments were required to compensate for the lack of "seat-of-the-pants" perceptions.

There was discussion over incorporating an electronic ADI symbol overlaid on a TV picture from the on-board sensor. It was determined that with high-speed vehicles, the operator lacked sufficient time to study the controls and readouts. During simulated maneuvering of the UMV, the "banking " TV picture strongly suggested a physical feeling of being in a rolling aircraft, although the console was quite stationary. There was a noticeable tendency for observers and operators facing the video screens to "bank" themselves with the picture. The visual system used a 500 line monitor to present the on-board picture to the operator. Use of color at that time was not considered worthwhile. With the technology available, use of color would have resulted in reduced resolution. Contrast appeared to be the more important operator cue. According to their results, pilot operators tended to use the video system more than weapon system operator (WSO) operators, who appeared reluctant to pull away from the plotter. Pilots seemed most adept on missions requiring low-level navigation skills. (8,62-66)

- NASA. NASA was also exploring the use of UMVs for aerodynamic research. In late 1972, NASA received the go-ahead to proceed with the first phase of the Remotely Piloted Research Vehicle (RPRV) program. Its purpose was to use UMVs to explore high angle-of-attack flight, stall, and spin for the F-15 fighter. The F-15 tests would be the first demonstration of the ability to use RPRVs for research into advanced flight. By 1973, NASA had developed a ground control loop that enabled an experienced pilot to remotely fly the vehicle. The addition of a computer in the ground loop made it possible to precisely control the aircraft under conditions of minimal stability. (9,67-71)

### 2.4.2 Industry Initiatives

- RCA. One of the major pushes by RCA in the mid 1970s was to put enough on-board equipment into the UMV so that it could

automatically fly most of its mission. The operator would be in the loop only as a monitor. In this scenario, the UMV might send back only a few video snapshots when it arrived at the terminal area. There would be just enough information to correct for any minor navigational errors. During the 30-60 seconds terminal phase, it was believed that the operator would need at most three pictures to get a final fix on the target. The enroute navigation aid would be based on the mission. Inertial navigation would function on short missions where the cumulative errors would not exceed permissable limits. At the time it was suggested that Loran be used for the longer missions. (While LORAN is subject to jamming, incorporation of the Global Position System (GPS) avoids this issue.)

The theory was that sufficient enroute vehicles might permit one operator to handle as many as a half dozen UMVs with proper displays during the enroute phase of the mission. Although the RCA concept was to reduce the manpower requirement during the enroute phase of the mission, RCA recognized that an operator in the loop was ideal for recognizing targets and for decision making.

On the one hand, RCA recognized the need for an operator in the loop. On the other hand, communications had to be free of jamming. RCA was willing to recommend that short missions be flown automatically as much as possible in order to reduce expensive data links and thereby reduce the vulnerability to jamming.

In terms of displays, RCA explored the use of cathode ray tubes (CRT) to display video and text information. During the enroute phase, the display might show tracks and associated alphanumerics, changing in the terminal phase to a split display of video or infrared, over which a cross hair designator could be positioned. In addition, the CRT would provide an alphanumeric display of flight status information along with a plan position indicator type of display. (10,46-47)

• General Electric. Coincident with RCA's efforts, General Electric Co.'s (GE) Aircraft Equipment Division was also looking at control stations. The GE approach was based on the belief that pilots made poor operators of UMVs. Their reasoning was based on the assumption

that the pilots were not comfortable flying by exception. It was their belief that a WSO might perform better using a control offset system.

GE's concept for UMV control called for extensive automation of the UMV controls in order to reduce the need for enroute communications to correct errors or perform other basic "housekeeping" functions. The objective was to keep communications to a minimum. Enroute, the operator would only be given exception data calling for corrective action. In the terminal area, much more information would be required which would result in opening the communication bandwidth.

Preprogramming much of the flight would eliminate communications except for operator updating. At intervals, the vehicle would send back a burst of data on progress. It was expected that sensor packages could be built that would allow the operator to identify and track the selected target within 15 seconds after the UMV arrived in the terminal area.

GE included computer generated imagery in its UMV concepts. One concept was to incorporate color-coded faults or discrepancies for specific vehicles when more than one vehicle was under control of the same operator during the enroute phase. (10,48)

- United Aircraft Corp. United Aircraft Corp's Norden Division advocated the use of color displays for alphanumeric data as a means of reducing display clutter. Norden concepts also included on-board data reduction. The system would monitor selected parameters in a status identification-display-system type of presentation, providing monitoring and failure prediction. (10,48)

- Grumman. Grumman specialists proposed an operational scenario where one operator would control a substantial number of vehicles during the enroute phase. Handoff would occur once the vehicle entered or neared the terminal area. Its was Grumman engineering's feeling that WSOs would be the best UMV operators because they tended to show less stress in electronic warfare environments than did pilots. Others at Grumman were promoting the idea that air traffic controllers were the best qualified to control multiple UMVs during the enroute phase. (10,48)

• Sperry Univac (UNYSIS Today). As part of the Pave Strike program in the mid 1970s, Sperry Univac proposed an improvement in the USAF/Univac APW-23 single vehicle control system which had first been demonstrated at Hill AFB back in 1973. The improved version incorporated software changes and changes in drone acquisition techniques to lessen operator workloads. Their findings were a direct result of earlier testing.

The original Univac multi-UMV system was developed to support the USAF Combat Angel program In this program, UMVs were used to dispense chaff and screen tactical aircraft. Originally, only three UMVs could be flown in a given area at one time, and each vehicle required a separate UPX-3 microwave command guidance system station. The development of a new APW-26 transponder, provided more identity codes, and enabled a total of 20 vehicles to be operated in a single area. However, each vehicle still required a separate director station.

According to Univac engineering, the most critical difference between single UMV and multiple UMV control is time. In a single UMV system, the vehicle is acquired and tracked continuously, and the control system provides tracking, telemetry, and command functions on a dedicated basis to the single UMV. For multiple UMV control, the control system must be time-shared. The operator must, via the control station, acquire the vehicle, track it to determine position and flight data, make any required decisions, and then move on to acquire the next UMV. For the control station to be able to present required data on each vehicle whenever that vehicle is selected, requires regular updates. To look at 20 vehicles once every 50 milliseconds, requires a phased array or multibeam antenna on-board the airborne control station. A visit to each UMV every two seconds allows use of a less expensive mechanically steerable antenna.

The system tested in 1973 incorporated a UYK-15 mini-computer, an adaptation of the UYK-20, a computer produced by Univac and accepted as a Navy standard. The computer allowed the control station to perform three vital functions:

(1) Predicting UMV location based on its last reported position, programmed flight profile, and any corrective commands that

had been transmitted. Control was possible over 360 degrees at ranges up to 200 miles.

(2) Acquire the UMV, via a radar designed to interrogate the UMVs transponder, with the airborne antenna being oriented in azimuth and elevation to the predicted UMV position.

(3) Update the airborne electro-mechanical plotting board, to show position of each UMV, as well as updating the two CRT data displays.

If the system was unable to acquire the UMV in its predicted location, and failed to locate the UMV after the computer initiated a sector by sector search, the ARCO was automatically notified.

This system could confirm the position of up to four UMVs every 12 seconds and read out their critical flight data when the vehicles were randomly distributed over a 60 degree azimuth and within 3 degrees of one another in elevation angle. Time required to transmit corrective commands or to initiate a search for one or more of the UMV would slow down cycle time.

The system provided two CRT displays each of which was used to display flight data from up to four UMVs (See Figure 2-2). Up to eight channels of proportional type data were available and an additional 16 channels of on/off type data could be presented.

Some information like pitch or roll angle was displayed in analog form. Other data such as fuel remaining or engine rpm was displayed in bar-graph form. Still other information was displayed in alphanumeric form. The data from the UMV most recently acquired was presented with more intense illumination.

After launch, the system plotted each drone's actual position so the ARCO could compare it with the intended flight path and, where necessary, introduce corrective action commands. One of the lessons learned in 1973 was that the ARCO had considerable difficulty in monitoring and controlling more than four UMVs at a time.

This prompted Univac to introduce increased automation into the system by programming the computer to perform more of the monitoring and to alert the ARCO only when a situation required his intervention.

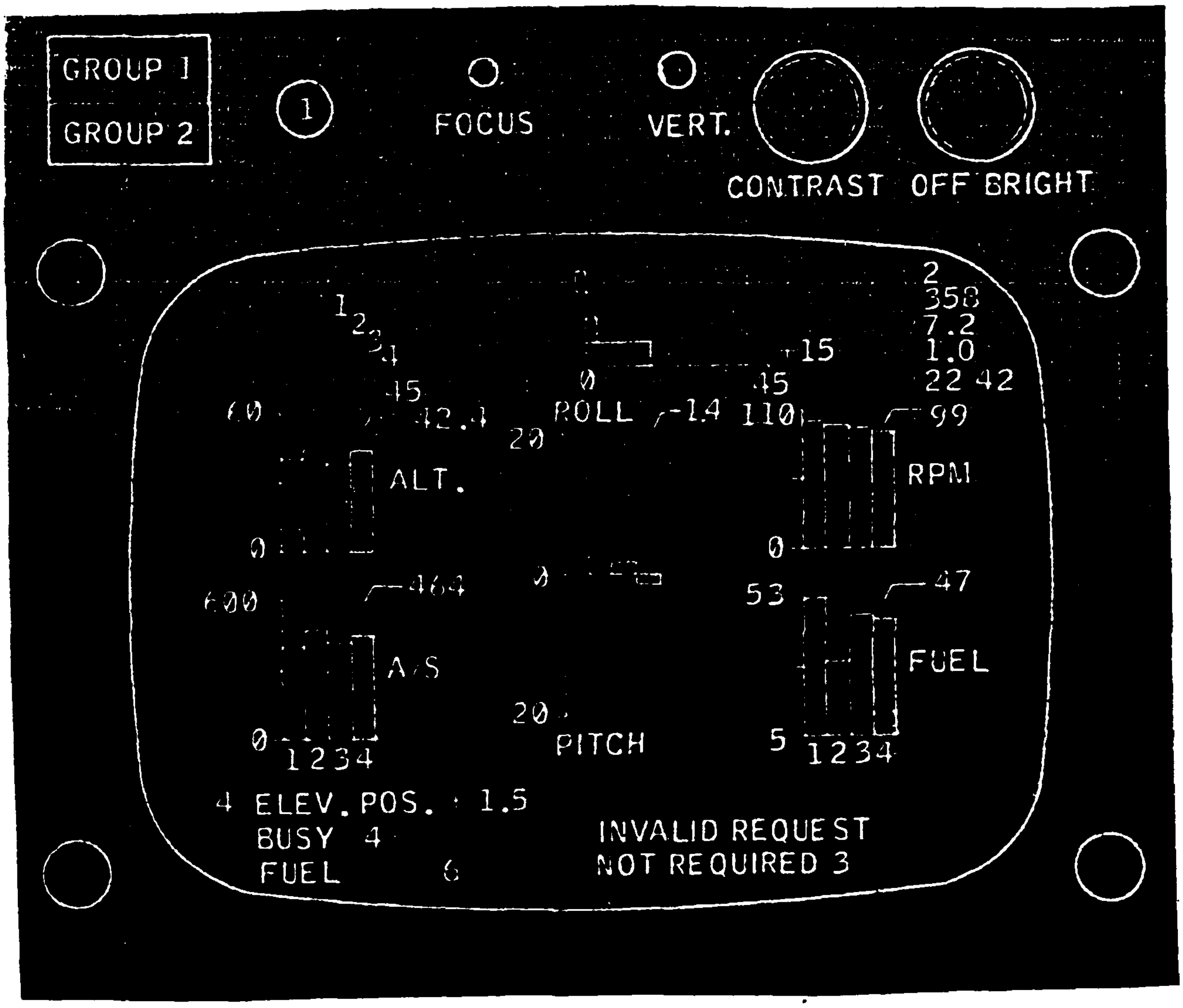



FIGURE 2-2 SPERRY UNIVAC DISPLAY SHOWING DATA FROM FOUR UMVs

Some of the problems encountered in the multi UMV tests resulted from inadequacies of the inertial navigation system installed on board the DC-130A launch aircraft. The aircraft's inertial navigation system is used for the initial heading and location of the UMV navigation system. These on-board navigation errors made it more difficult for the Univac computer to accurately predict the location of each UMV, which in turn introduced delays in acquisition/interrogation cycle time. (11,57-62)

• Decision Sciences Inc. (DSI) (Lear Sigler today). DSI of San Diego conducted an extensive study in the mid 1970s. For this study, DSI used five types of subject operators:

(1) People with no piloting experience, but with automobile driving experience.
(2) Engineers with knowledge of flight control principles, but without pilot training.
(3) Experienced model aircraft operators.
(4) Volunteer Navy fighter pilots from Miramar Naval Air Station, California.
(5) Volunteer Navy attack aircraft pilots from Lemoore Naval Air Station, California.

The control station contained a 21-inch CRT display for the TV camera's view of an aerial photograph that moved to simulate UMV motion. Also, the control station had a conventional aircraft two axis attitude direction indicator (ADI), a horizontal situation indicator (HSI), airspeed and vertical velocity indicators, an altimeter, a sideslip indicator, a g-force meter and a control surface position indicator.

The controls included a pitch/roll attitude stick, rudder pedals, pitch/roll trim controls, and a side-stick camera pitch/roll plus a switch to control TV zoom.

One purpose of the experiments was to determine optimal control techniques. Sometimes, the optimum control technique depended upon the background of the operator, but in other cases, other techniques were superior for all operators. As an example, a position control stick was superior to the basic rate command even though the latter is equivalent to conventional aircraft controls. Although the Navy pilots benefited the least from the position stick, all operators benefited

because it gave them an intuitive feeling for vehicle attitude, and reduced their need to depend on the UMV displays.

DSI evaluated a display technique where pitch axis attitude was shown from the "outside-in" and the roll attitude was displayed in the more traditional "inside-out" manner. DSI concluded that a display providing an outside view looking into the vehicle was superior for controlling pitch and altitude, while the traditional inside-out display was superior for roll-axis control.

An interesting point in this study was the evaluation of the delay inherent in the communication links. All UMV control stations have some delay between the sensor receiving an input and the results showing on the operator's monitors. This led DSI to explore the use of predictive technology. Using predictive technology, the display would show pitch and roll attitudes as they were predicted to be in the near future as opposed to their current setting. The study indicated that operators had difficulty in using the feature. Apparently, they were already compensating for the delay, so the incorporation of the predictive feature only confused them. DSI therefore decided not to pursue predictive technology.

Another factor bearing on the choice of display technique was the mounting of the television camera. The television could be mounted on a stabilized platform or it could be fixed mounted to the UMV. With a stabilized platform, the operator could not judge bank/roll or pitch/attitude using the video monitor as a source of information. DSI concluded the operator performed best when the UMV's television camera was fixed to the airframe during the enroute portion of the mission, and in a gyro-stabilized mode when operating in the terminal phase of the mission. The zoom capability associated with the TV camera was helpful when used to zoom in on a target and zoom out to increase the field of view. However, the operators could become disoriented when zooming the camera while slewing the camera simultaneously to a different azimuth-elevation angle.

The very low altitude requirements of many of the UMV missions magnifies the consequences of operator error or disorientation. DSI's study concluded that the mixed display combining the inside-out

roll-attitude display and the outside-in pitch attitude display, and superimposing them upon the CRT image from the TV camera reduced the number of erroneous control inputs by the operators.

DSI also suggested two additional areas for study: using enroute operators who pass off control of the UMV to terminal operators, and how to train non-pilots to fly UMVs. (12,49-50)

### 2.4.3 Operational Systems

• Compass Cope. The objectives of the Compass Cope program were to design, develop, and test two high altitude sensor platform vehicles. The program consisted of the Boeing YQM-94A and the Teledyne Ryan YQM-98A. Both vehicles used conventional landing gear to permit runway takeoff and landing.

Boeing's Compass Cope vehicle command module consisted of standard cockpit instrumentation, data link equipment, a television screen, and a navigation display. Data link components included the APW-26 airborne transceiver, microwave command guidance system, wide-band microwave data transmittal system for video, and a TPW-2A X-band radar van.

The Boeing Compass Cope vehicle had an automatic guidance system that permitted total or partial pre-programmed missions, permitted maximum evasive maneuvers, provided safe control and recovery in the event of loss of carrier, and reduced the operator's workload by assuming the tasks of guidance, event timing, and progress monitoring. If the operator wished to "fly" the vehicle, he could specify altitude, airspeed, Mach number, heading, or program a waypoint. The vehicle was designed for single control, but almost always during demonstration, Boeing used extra personnel for assistance. (13,81-83)

• Aquila and its Predecessors. In 1974, the U.S. Army began the Aquila program. As built by Lockheed, the Aquila was designed to operate in the microwave crowded skies over Europe. The Aquila has a complex secure data link, including two steerable antennas in dorsal and ventral thimble radomes. It has its own inertial navigation system. Finally, Aquila was designed for fully automated recovery, which required the development of a special electro-optical guidance system to steer the vehicle into the landing net. (14,1773)

In the Lockheed Aquila, the operator's technique plays an important role. Normally, the Aquila flies an automatic figure 8 orbit, while designating a target with a laser beam to guide incoming Copperhead artillery rounds. The spot location is affected by the figure - 8 orbit, and the operator must manually compensate for this effect. Operators also have the ability to use the laser designator as a ranging device. The operator can range on the crater of the first shell and the system will automatically compute range, deflection, and elevation corrections, and relay that information back to the artillery battery. (15,101)

For one early Aquila system known as the Aequare, the Lockheed-designed flight control systems performed both the aircraft stabilization and flight path control, or autopilot functions. The autopilot functions were controlled from the ground through the military G-band telemetry uplink. The operator could only input altitude, airspeed, and heading commands. Vehicle stabilization loops were closed with the flight control package and therefore were independent of ground control. Feedback to the operator was provided through the air data package, rate gyro, directional gyro, and flux gate compass.

Vehicle guidance was by means of waypoints along a preprogrammed flight path, which the UMV operator could update while the vehicle was enroute to the next waypoint. The aircraft's progress was portrayed on an X-Y plotter that had a map behind it to help the operator follow the waypoint navigation.

The ground control station were designed for both a vehicle and a sensor operator. The control station was also designed for non-pilot operators. (16,40-42)

As part of the Aequare program, Lockheed Missiles and Space conducted a feasibility program to demonstrate the ability to designate a target with an operator stabilized laser designator mounted on a UMV. The Aequare was launched from an F-4 aircraft at an altitude of 25,000 feet. After launching the UMV, the F-4 would climb to 35,000 feet and assume the role of relay between the UMV and the ground control station located at Kirtland AFB, about 140 miles away.

Once the UMV was launched, it performed a series of preprogrammed maneuvers and then executed a series of climbing turns until the vehicle was acquired by the ground control station. After acquisition, the operator could change the altitude, speed and heading of the vehicle, and choose between 3 deg/sec and 6 deg/sec maneuvers. The actual control of the vehicle flight surfaces was controlled by the on-board autopilot. If the data link was interrupted, the UMV immediately instituted the climbing turns until it could be reacquired.

With the Aequare project, Lockheed had already developed a sophisticated capability to designate targets. An attack aircraft with laser guided bombs could use its radar and the UMV's radar to determine the relative location between the aircraft and the UMV. The ground station would provide the attacking aircraft with X and Y offset angles from the UMV to the target, which would enable the attacking aircraft to launch its weapons. The UMV payload operator would then designate the target with the laser. While the operator focused the cross hairs in the display on the target, the laser provided the range from the UMV to the target. The stable platform on which the laser designator was mounted provided the azimuth. The ground control computer used this data to continually calculate the X and Y offsets, which were provided to the attacking aircraft by a standard UHF data link.

Lockheed's 1974 Aequare project demonstrated that a single non-pilot operator could control a UMV at distances up to 200 miles. Their concept resulted in a much simpler MMI than the consoles than being used for pilot controlled UMVs. The plan was for the operator to know the current status of the bird, what it was doing, where it was, and what it saw. In turn, the operator needed only to command heading or altitude or speed, or the mode to operate in. The responses of the vehicle were automated.

There is one other aspect of this UMV to consider. Once a target was designated, flight control of the vehicle was automatic. The change in look down angle of the stable platform initiated the turns as the vehicle flew a programmed race track. (17,64)

• Phoenix. The British Phoenix program of the 1970s followed a different approach. The users defined the required information, the battlefield conditions, and the expected targets. These requirements dictated the type of sensor required, which drove the design of the system toward successfully getting the sensor to the target and exploiting the available sensor data. The Phoenix ground control station required three crew members. The operations called for a mission operator, a UMV operator, and an image interpreter. The ground control station was menu driven to minimize workload. The system had the ability to combine the digital map displays with UMV track and position, and the sensor field of view. The operator got a view superimposed on the actual terrain. (14,1774)

• Pioneer. Besides the Army Aquila program, the only other U.S. program involving flyable hardware is the Navy Pioneer program. Currently, testing of the Pioneer vehicle has been suspended while the Navy and the contractor, AAI, determine a better method for retrieval. Three of the five vehicles purchased by the Navy have been destroyed upon landing. A fourth unit never returned from its mission. The shore based Pioneer 1 ground control station can be mounted in a standard S-250 modular shelter mounted on a truck bed, or it can be divided and carried on two high-mobility multipurpose wheeled vehicles (HMMWV). Portable stations, consisting of three items with a total weight of 130 pounds, are also available. The concept is to locate the portable ground stations with forward locations to allow for good line of sight when control of the UMV is passed from the main ground support station. (18,109)

• Numerous other UMVs are currently under development in the United States and other countries. A description of each of those systems is beyond the scope of this report.

## 2.5 Summary of MMI Issues

The MMI issues identified parallel many of the human factors engineering issues found in manned aviation research. This is expected due to the parallel development of piloted aircraft and UMVs.

Early problems dealt with control and display integration and workstation design for effective operation. However, an issue not found in piloted aircraft was who the operator should be - pilot or non-pilot.

Other issues such as UMV visual range limitations were eliminated as communication and flight control technology improved.

As control technology including automated flight technology improved, other MMI issues emerged. The simple X-Y mechanical plotter gave way to more sophisticated displays capable of providing UMV attitude and altitude information, thus providing operators with effective vehicle orientation cues. Visual imaging systems provided remote viewing capabilities, but with limited resolution and stabilization needs.

Recent MMI issues emerged from more sophisticated mission capability and computer technology. Where there might be only one operator, a UMV now could require a crew to fly the vehicle and control the sensor payload. Allocation of duties, response time, and operator accuracy increased in importance. With increasing range, UMV control became a problem due to system lag times. Predictive displays and control theory/stability analysis became critical.

Finally, technology made automation possible, shifting, but not reducing workload. While a UMV could "run by itself", detection of navigation errors and other system parameters proved difficult. Any errors, no matter how small, could significantly degrade operations. Thus, the major issue of manual versus supervisory control appeared for UMVs as it did for piloted aircraft.

The MMI issues identified in this section are summarized in accordance with the type of control station i.e. those using visual feedback, those with radar tracking, and those with video tracking:

Visual tracking control MMI issues:

- Attitude determination with visual cues.
- Pilot operator versus non-pilot operator.
- Control Reversal- direction towards/away from the operator.
- Visibility and visual range of UMVs.
- Rate versus proportional versus position control.
- Operator accuracy.

Radar tracking control MMI issues:

- Workstation controls and displays (e.g. Quantity,type, and analog versus digital display layout).

- Position plotting- type of plotter, and UMV orientation and visualization.
- UMV response time.
- UMV communications.
- Manual versus supervisory control
- Operator error detection and correction

Video tracking control MMI issues:

- Visual imaging systems (e.g. resolution, color, stabilization, and computer generated overlays).
- Visual displays (inside-out versus outside-in displays).
- Operator workload.
- Crew size.
- Allocation of duties.
- Mission demands/critical flight phases.
- Predictive versus Real-Time (Delayed) Displays.

## 3.0 MAN-MACHINE INTERFACE ISSUES

The evolution of the MMI design can be traced to the incorporation of different technologies. The earliest UMVs were visually tracked. These systems were never flown from the line of sight of the operator. Therefore the MMI was considerably simpler compared to the MMI designs of the more sophisticated systems. The incorporation of radar, automatic flight controls, and an X-Y plotter for indicating location added to the complexity of the MMI design. Finally, the incorporation of television cameras and the need for a video downlink, effectively doubled the operator requirements and significantly added to the MMI equipment. For this reason, detailed discussions of the MMI designs will be divided into these three areas.

### 3.1 MMI Issues for Visual Control Based Systems

This subsection further explores six different MMI issues or design drivers identified in Section 2. Compared to the MMI issues associated with radar controlled and video controlled based systems, these MMI issues are relatively simple. From a technology perspective, very little can be done to resolve these issues except to ensure that operators receive sufficient training and opportunities to practice what they have learned. Just like flying a manned aircraft, controllers need regular practice to maintain their skills.

#### 3.1.1 Attitude Determination With Visual Cues

With these types of UMVs, all status information of the vehicle, such as pitch attitude or bank attitude has to be determined visually. Some people have trouble with the visual cues. Early trainees might react to visual cues with body English, but this lessens as training progresses. The lack of stability of the control box has not been a problem. Paint schemes such as Radioplane's white and red wings can be of tremendous assistance to the operator in determining vehicle attitude. Some operators believe determining angle of attack is the major problem with these systems. Other operators believe the major problem is the inability to judge bank of the wing. Engineers at Northrop believed that pitch is more stable compared to roll. (21) The solution to the issue of determining vehicle status and attitude using

visual cues is training. Operators with good eyesight have an advantage over less fortunate operators, but using visual cues to determine vehicle attitude and status is a skill that has to be developed.

### 3.1.2 Pilot Operator Versus Non-Pilot Operator

The issue of who makes the best type of operator is an open issue that often degenerates into heated debate. The issue is as old as UMVs. Consider Admiral Fahrney and his team of Navy pilots back in the 1930s exploring remotely controlled full size aircraft. At the same time, Reginald Denny and the Radioplane people, mostly non-pilot operators, were flying small target vehicles. The pilot operator has extensive knowledge of flight principles and generally better understands how the air vehicle responds. On the other hand, the pilot has learned to determine vehicle status and attitude with motion cues that are not available to the UMV operator. In addition, the pilot's normal environment is to be inside the aircraft looking out, as opposed to being outside the aircraft, looking in. The non-pilot operator does not suffer from these negatives, however, his knowledge of flight control principles may also be weaker.

In reality, it really does not matter who operates the UMV. What is important is that the operator must have a solid understanding of the vehicle, and its capabilities. The operator should know how the vehicle responds, and should know the limits of the flight envelope. Steadiness of hands, good hand and eye coordination, and the ability to withstand the stress associated with flying UMVs are the most important attributes for the operator. (21)

### 3.1.3 Control Reversal

Two aspects of control reversal merit discussion. First, when landing a UMV, the recovery operator is usually stationed just off the runway and near the touchdown point. On final approach, the operator is facing the nose of the vehicle. A left turn command will cause the vehicle to roll to the operator's right. It is readily apparent how a mistake made by the operator at this point can lead to an accident and possible loss of vehicle. The operator must remember that the vehicle will respond in a manner opposite to the movement of the control stick.

The second aspect of reverse control occurs after landing. After the vehicle has touched down and rolled past the operator, the operator turns and is facing the tail of the vehicle. Now the vehicle and the control stick will operate in the same direction. The critical point occurs at the point where the vehicle passes the operator. At that point, the control of the vehicle transitions from "reverse control" to "normal" control.

The literature did not identify methods to avoid this problem when using only visual cues to make the landing. On the other hand, with a little bit of training, the situation is not too difficult. Most experienced operators do not have a problem with control reversal, but every so often, one will make a mistake.

3.1.4 Visibility And Visual Range

The visual control system has been defined as external observation linked to direct command of control surfaces. The operator's control box fits into the palm of one hand, while the other hand manipulates the joystick. At the same time, the operator's attention is focused on the vehicle in order to receive the visual cues. The flexibility of the mission to be flown is dependent upon the eyesight of the operator. The range the smaller vehicles can fly is between 1 1/2 and 5 miles. The incorporation of position control does allow the vehicle to fly beyond visual range, as long as the operator knows how to make a 180 degree turn without any visual cues. Position control allows the operator to put the vehicle into a specified bank, and the operator already knows how long it takes the vehicle to complete a turn with a given bank angle. With a rate command system, this would be impossible.

One procedure for control beyond visual range is to have two operators. The first individual is responsible for local launch. The vehicle is either automatically or manually commanded to fly to the mission area. In the mission area, a second operator with a transmitter tuned to the control frequency, can take control of the vehicle through its mission tasks. Upon completion of the mission tasks, the forward operator can vector the UMV to the recovery area. (22)

### 3.1.5 Rate Versus Proportional Versus Position Control

The early Radioplane control system involved rate commands. These rate commands are tricky for inexperienced personnel. Each command has to be countermanded in order to restore the flight control surfaces to neutral. As long as the joystick makes contact of any sort, the control station sends a continuous command, such as left bank. In addition, the operator usually has to input up pitch in order to maintain altitude during the turn. (4)

The incorporation of the vertical gyro came in the early 1950s. Northrop claims the first application of an autopilot with the incorporation of the E-16 vertical gyro which was connected to the aileron. The next change in MMI came about as a result of incorporating an altitude hold capability. With this hardware, the UMV can remain at a constant altitude, and the operator does not need to incorporate Up pitch during a turn. This also means that position commands instead of rate commands may be used. The control box can be used to input selected levels of bank such as 10 degrees or 30 degrees. Northrop's control box design has remained relatively steady for twenty-five years. See Figure 3-1.

Many of the UMVs today use proportional control similar to that found in manned aircraft. The attitude assumed by the vehicle is proportional to the displacement of the control stick from neutral. Movement of the stick results in commands being sent to the flight computers on-board the vehicle. The flight computer causes an adjustment in the vehicle flight control surfaces so that the vehicle assumes the proper attitude or altitude. Pilot operators prefer control stations with a stick and as a group, are the most comfortable with proportional control.

None of these three control designs seem to be a problem for operators. With the proper training and a little practice, most operators can become proficient with any of the three methods. There is evidence to suggest that position and proportional control systems are simpler to fly, and beginning operators can master these two systems much faster than they can master a rate control system. As for MMI issues, the type of control is not as pressing as some other MMI issues.

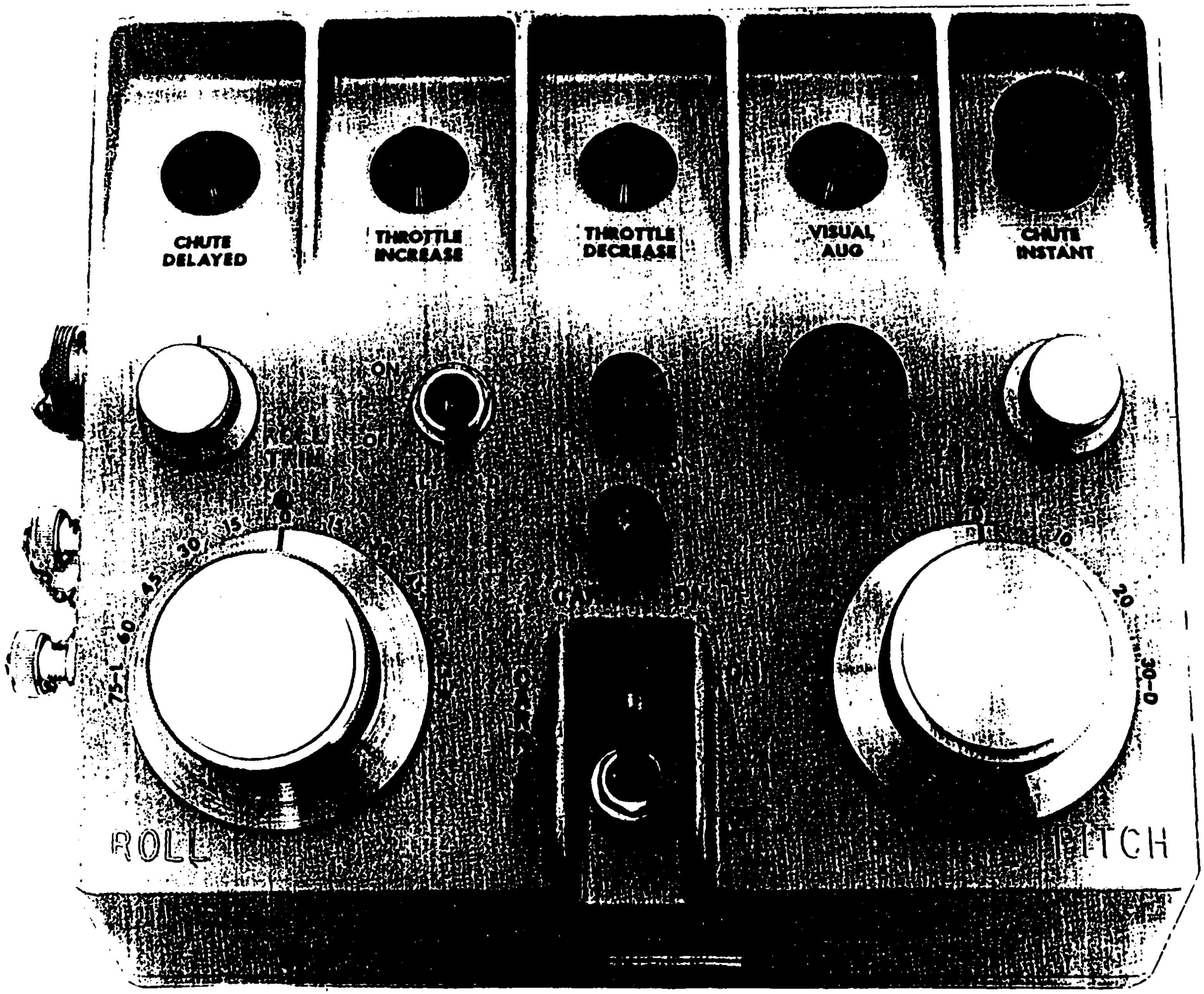



FIGURE 3-1 NORTHROP CONTROL BOX

### 3.1.6 Operator Accuracy

Operator accuracy refers to the ability of the operator to input the right command at the right time. There are several indications in UMV mishap reports of operators sending the wrong command or failing to send the vehicle a correction command. The most difficult aspect of flying these vehicles today is when the recovery sequence involves a conventional landing. All flight control surfaces are manipulated during the landing, and the operator can not afford any mistakes. There was no data to indicate that operator accuracy is affected by a control station whose design represents poor human factors engineering. There is data to indicate that becoming proficient at conventionally landing UMVs requires substantial operator training.

## 3.2 MMI ISSUES FOR RADAR CONTROL BASED SYSTEMS

This subsection discusses six additional MMI issues first introduced in Section 2. These six MMI issues are a result of incorporating the necessary technology to allow the UMVs to fly beyond visual range, and to communicate flight status and attitude information to the control station.

### 3.2.1 Workstation Controls

It is necessary to add equipment to the control station so that the UMVs may fly beyond visual range for extended periods. A plotter is usually used to show position of the UMV. A typical plotter measures 30" by 30" and uses two pens. The first pen can be used over a geographic map to show the location and plot the course of the UMV. The second pen indicates altitude. Trained operators rarely have difficulty in visualizing the vehicle in 3-D space. Many times though, operators are unsure if the UMV is responding to the commands. Depending upon the fidelity of the plotter, operators can end up over-controlling the vehicle in order to receive feedback on vehicle heading.

Other flight instruments can be added to the control station. A navigation package available from Vega provides airspeed, altitude, roll, and pitch. Motorola developed the Integrated Control and Tracking Station (ICTS) autopilot. With ICTS, pitch, air speed, engine RPM, and roll can be downlinked to a gyro ball- altimeter readout - airspeed

readout. Engine RPM is transmitted to the operator as a percentage of available RPMs. The proportional control stick uses fly by wire with separate pitch and roll trim controls off to the side. The ICTS design reflects the incorporation of some human factors principles. (4)

Northrop has developed the Northrop Aerial Target Tracking System (NATTS). This system has been used for over 15 years. The system can provide the operator with real-time target data such as range, azimuth, altitude, and airspeed. It operates in a customer specified discrete frequency range between 1650 and 1670 MHz. NATTS consists of an antenna assembly, and a computer display unit. Figure 3-2 shows a picture of the NATTS system. Performance of this system is as follows:

Range .1 km to 110 km (.05 to 60 nmi)
Azimuth: 360 degrees
Altitude: 150 to 12,200 m (500 to 40,000 ft)

NATTS is very portable and as a result, can be used in a variety of situations. A typical installation of NATTS is shown in Figure 3-3. The system is set up for field use, but can be stowed in carrying cases, ready for transport. A special version of NATTS has been developed specifically for use aboard ship. The shipboard version of NATTS provides heading compensation to the target display unit for changes in ships course. (23)

3.2.2 Position Plotting

The incorporation of the position plotter has had more impact on the MMI than the incorporation of the flight status displays. Operators must develop the necessary skills to visualize the vehicle's pitch, bank, speed, and heading using either the individual displays, if the station is so equipped, or the plotter. When using the plotter, the operator has to mentally integrate information from two moving pens. The first pen marks the vehicle's range, distance, and over time, shows the heading. The second pen indicates altitude. Usually a separate strip chart or an area off to the side of the plotter is used by the "altitude" pen. As a general rule, pilot operators have a harder time transitioning to the plotter than non-pilot operators. Fortunately,

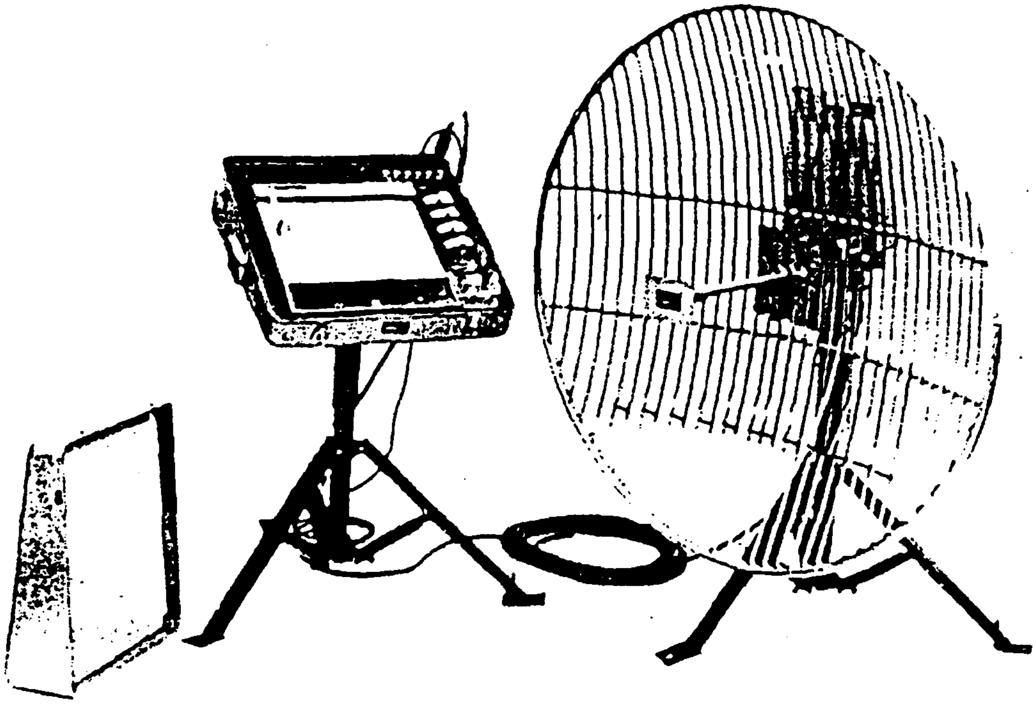
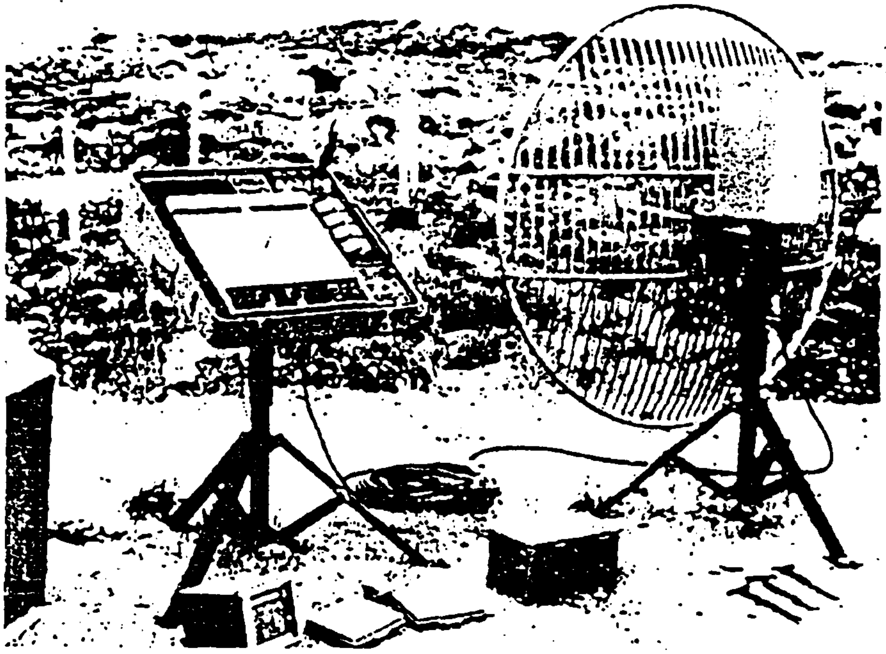
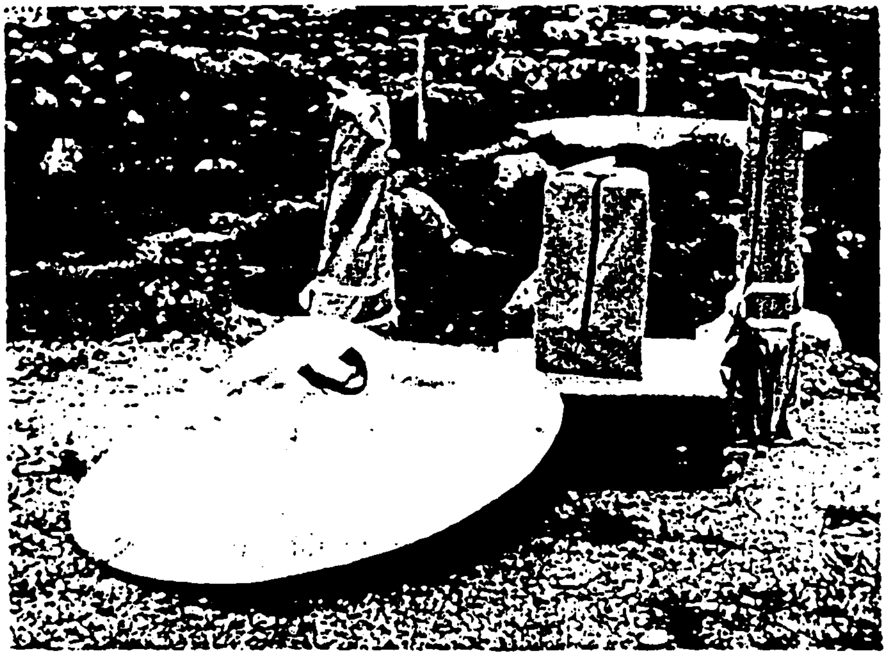


FIGURE 3-2 NORTHROP PORTABLE AERIAL TARGET TRACKING SYSTEM



NATTS FIELD INSTALLATION



FIELD SETUP

FIGURE 3-3 INSTALLATION AND FIELD SETUP OF NORTHROP AERIAL TARGET TRACKING SYSTEM

Northrop has demonstrated the ability to tie the control station into a computer that can simulate the movements of a UMV and manipulate the control station as if a real flight were in progress. This way, operators can practice specific skills at any time, and under any conditions.

### 3.2.3 UMV Response Time

Depending upon the communications link and the distance between the operator and the UMV, the response time of the UMV could exceed two or three seconds. Consider a situation where communication between the operator and the UMV takes half of a second. The vehicle must then comply with the command, and as part of its status update, report the change back to the ground. Assuming a one second response time on the part of the vehicle, over two seconds will transpire before the operator learns if the vehicle has responded correctly.

In the early 1970s, Boeing demonstrated the ability to control a UMV located in one state from a control station several hundred miles away in another state. They used a commercial communications satellite for the data link. They also performed the necessary calculations to establish the feasibility of controlling a UMV anywhere in the world using two satellites for communication relay. As part of this effort, Boeing also measured significant communication delays. Commands to the UMV took over a second, the vehicle had to respond, and a status update took over a second to get back to the controller. Using two satellites would effective double the communication time. As a result of the UMV response time, operators are at a disadvantage when control of the UMV requires feedback from the first command, before a second command can be sent. (21)

To date, the method used by UMV designers to avoid this issue has been to increase the automation on-board the vehicle. Having the UMV close many of the control loops simplifies the need for communication between the operator and the UMV. The increased automation means less emphasis on control, and more emphasis on monitoring flight status.

### 3.2.4 UMV Communications

Today, there is an increased need for protection of the communication link. Disruption of the link, especially the payload data

link, by active or passive means, renders the less than fully automatic UMV useless. Twenty years ago in Southeast Asia, the operators of the reconnaissance UMVs were not worried about communications being jammed. The communication link was always "on" and beaconing. This luxury is no longer affordable. Communications between the UMV and the operator must be of limited duration. Secure communications are available, but only at the expense of the MMI.

One of the major developmental problems with the Aquila was integrating the operator and his movements at the console to the movements of the vehicle. Because of its secure data link, the Aquila does not send back its video in real time. Many times, the operators would react to an image on the screen as if it was happening at that instant. The result would sometimes be an incorrect command to the Aquila. This delay in video image requires the operator to anticipate where the vehicle is based on a view of where the vehicle was. (24,38-43)

### 3.2.5 Manual Versus Supervisory Control

With automated flight systems, the role of the operator is reduced from controller to monitor or supervisor. Like communications, this issue has had a significant impact on the MMI design. Operators have to learn how to fly the vehicles by exception. That is, the operator will interact with the UMV only when the UMV has strayed from its programmed course, a change in the programmed mission is required, or the vehicle has had equipment failure that mandates the operator take manual control of the vehicle. Training operators to operate by exception represents a fundamental change. The operator uses fewer piloting skills and must develop problem recognition/solution skills instead. This issue is still current, and new automated flight technologies are being developed.

### 3.2.6 Operator Error Detection and Correction

With radar control based UMVs, it is necessary for the operator to develop the skills to identify vehicle problems using the displays available at the control station. No longer may the operator receive visual cues from the vehicle. Generally, these control stations reflect a heavy influence from pilot operators. Many of the flight status displays are the same or similar to those found in manned aircraft

cockpits. There is little data suggesting that flight status displays are being designed specifically for UMVs. However, there is also no data to suggest that the current displays are inefficient or should be replaced. The point is that pilot controllers seem to be more comfortable with the flight status displays of the control station, while non-pilot operators are more comfortable with the plotter. Non-pilot operators are at a disadvantage with these control stations. They have to learn the equivalent of flying an aircraft on instruments. Pilot operators, on the other hand, are already trained for instrument flying.

As there has been little activity to change the control displays, the short term solution to this issue is to ensure that training is sufficient for operators to learn how to read the displays, determine if there is a problem with the vehicle, and select and implement the appropriate response. There should be some research conducted on determining the degree the control station should mimic a normal aircraft, and whether changes in display formats and methods can improve operator performance.

### 3.3 MMI Issues for Video Control Based Systems

Video transmissions from the UMV to the operator can serve several different functions. Video may be used for reconnaissance, in which case the operator is interested in identifying potential targets and their location. Video may also be used for navigation, in which case the operator uses visual cues provided by the video camera to determine if the vehicle is flying the correct flight path. When used as a weapons carrier, the operator needs visual cues to determine when to launch the weapons. Finally, if the operator is attempting to land the UMV in a conventional manner, and is not in visual sight of the vehicle, the video cues provide the operator with most of the data required to set up an approach and make the landing.

#### 3.3.1 Visual Displays

Although there are several different uses for video from UMVs, there are numerous problems. The televised view lacks some of the characteristics associated with a direct view. In most cases, the view is monocular and is peripherally restricted. This two-dimensional

presentation also eliminates the important stereoscopic depth cue of retinal disparity as well as the powerful monocular cue of motion parallax. The monocular image also lacks textural information and is often not located at the correct distance from the pilot. These problems interact with the restricted peripheral vision and they can be considered in two aspects: (1) performance may be degraded by the presence of contradictory depth information. (2) performance may be degraded by the lack of complete physiological depth information. (25,12-16.)

It has long been known that landings with a television display are inferior to those made using either restricted peripheral vision or direct vision. As an example, consider the NASA F-15 Remotely Piloted Research Vehicle (RPRV) discussed in paragraph 2.4.1. Figure 3-4 shows the control relationships. For landing, the operator used the forward-looking TV as his main source of information. Altitude calls had to be provided by the chase plane. Since the vehicle was a controlled glider with no speed brakes, the operator took advantage of techniques developed from the lifting body programs to vector the aircraft for an approach to the dry lake bed. Experience on these landing indicated that the reliance on TV resulted in significant workloads for the operator. (26,36)

The major difficulty in landing a UMV with television displays is the estimation of exact height during the last few feet prior to touchdown. Part of this is caused by the restricted field of view, but there is also degradation due to poor resolution and depth of focus of the monitor picture. (27,4) There may also be distortions created by defraction effects of the camera lens. (28,271)

When employed in UMVs, indirect viewing systems also result in a lack of kinesthetic "seat-of-the-pants" cues. This lack of cues is in addition to the restricted peripheral vision and other disadvantages mentioned above, since the pilot is most often located in a stationary control center. This absence of kinesthetic stimuli particularly complicates the approach and landing task, since the cues derived from accelerations generated by wind sheer and turbulence are missing.

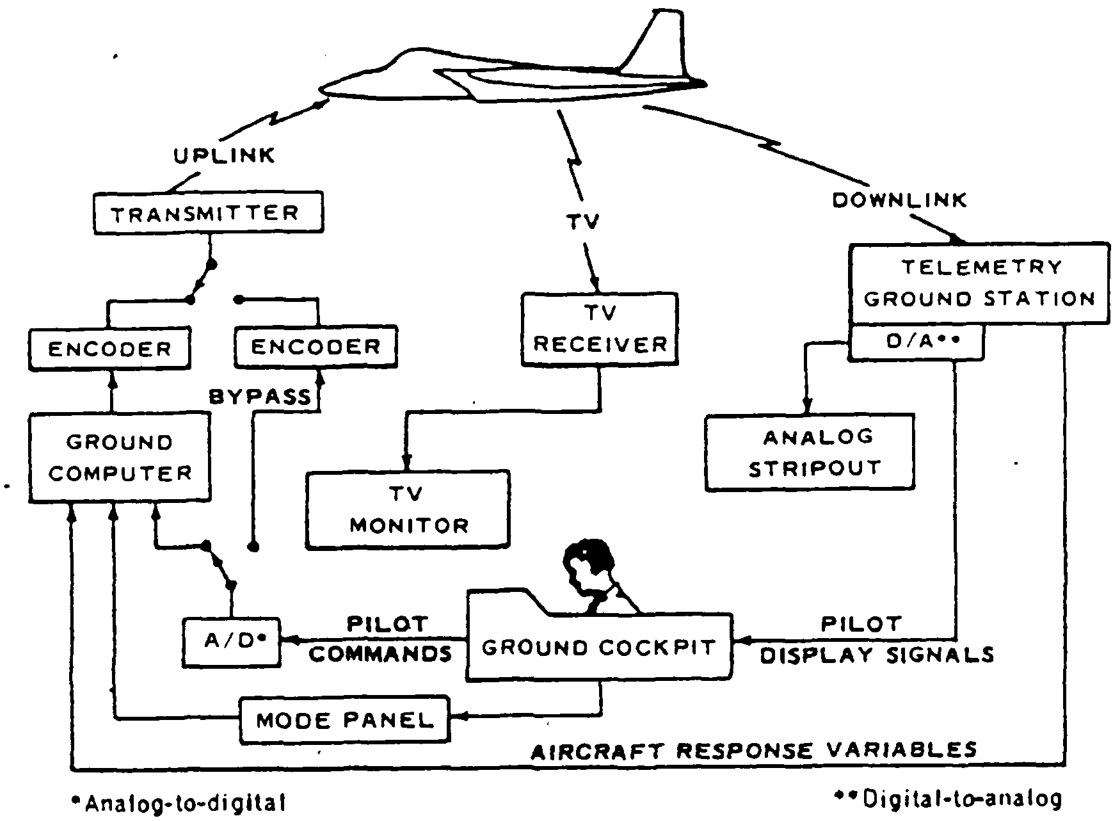



FIGURE 3-4 NASA F-15 RPRV CONTROL RELATIONSHIPS

(29,10) Part of what the display lacks is color. Better depth perception is obtained with color because color enhances object recognition, particulary in camouflaged situations where the objects have similar contrast ratios. (30,1) Additional altitude information in the form of a radar altimeter or computer-generated graphics appears to have little effect on landing performance. (31,1)

For approach navigation, pilots must learn how to determine their position from a two dimensional display with its inherently limited field-of-view. The landing flare for an aircraft with low to moderate wing loading is seen as a highly variable control task where the pilot simultaneously alters the altitude, flight path, and airspeed to arrive on the runway in a nearly stalled condition with zero sink rate. The landing condition is a zone where small variations are possible, but excessive variations in deceleration in the flare will result in floating (too little deceleration) or sinking (too much deceleration). The problem for the UMV operator is to recognize his position in time and space during a highly variable maneuver given an unfamiliar lack of cues. (32,34-35)

### 3.3.2 Operator Workload - Crew Size

There was no evidence of detailed studies exploring operator workload other than the studies trying to determine if a single operator can control more than one vehicle during the enroute phase of the mission. The operator workload of supervising the enroute portion of the UMV mission is relatively easy. However, significant workloads occur during the terminal phase of the mission when a real time data link is used for sensor payload data, when the activities of the UMV have to be coordinated with numerous individuals, or when conventionally landing the UMV. These areas should be investigated in some detail to determine if operator workloads can be simplified.

Some reconnaissance missions require the payload operator to seek out specific targets. Sometimes the only clues available to the operator are the images from a narrow field-of-view television camera flying at high speeds and at a low altitude. The operator has very little time in the target area to seek out and positively identify the target.

One of the major determinants of operator workload is the coordination required between the vehicle operator and others. The vehicle operator and the payload operator have to develop a close working relationship. In some cases, there is an additional person acting as mission commander. UMVs flying in support of, and in formation with manned aircraft significantly increase the operator's need to coordinate with other individuals.

The operators flying the NASA RPRVs learned that landing a UMV involves high workloads. The operator has to control the descent, the approach angle, the speed, and initiate a flare at the proper moment with the benefit of being on-board the vehicle. Landing NASA's F-15 RPRV required the operator have help from another individual on the ground and the pilots in the chase planes to call out UMV altitude. (26,36)

Operator workload can be reduced by the incorporation of additional automation and improved sensors. The artificial intelligence and information management technology being investigated for the Advanced Tactical Fighter may also contribute to reduced UMV operator workloads. Teledyne Ryan and Boeing have both demonstrated an automatic landing capability for UMVs.

# 4.0 TECHNOLOGY AFFECTING MMI DESIGN

Many of the MMI issues identified in the previous sections are still being addressed. This section describes current research efforts to resolve those issues, primarily those related to computer technology. These reseach efforts are flight control automation, communications, video transmission, and predictive displays. An additional issue deals with operator training. Although training is not specifically identified in the previous sections, it is an underlying problem, particularly where multiple operators are involved. With increasing automation, training assumes a greater importance.

## 4.1 Automation of Flight Control Systems

### 4.1.1 Background of Automation

As a result of the automation in flight control systems, UMVs no longer require direct human control during flight. Most of the non-target UMVs have autopilots and the capability to fly a complex mission without any intervention. In the early days, UMVs were under manual control. The historical trend has been from manual control to fully automatic control. The UMVs flying non real-time reconnaissance missions in Southeast Asia were preprogrammed and flew without human intervention.

However, many of the automated UMVs allow for operator intervention. The incorporation of automation though relegates the operator to supervisory control. Under supervisory control, the operator communicates with the on-board computer flight system, while the computer flight system through its sensors and actuators, implements the command and controls the flight surfaces. Today, there are UMVs that are strictly manual control, others that are fully automatic, and a host of UMVs between these two extremes.

Figure 4-1 shows the relationship between supervisory control, manual control, and automatic control. The first two drawings represent manual control. The first of these systems is without computer aiding while the second systems represents UMVs with computer controlled flight surfaces. In the more primitive systems, the radio receiver is connected to relays, which in turn activate the servo motors controlling the flight surfaces. With the incorporation of an autopilot and use of proportional control systems, the computer on-board the UMV

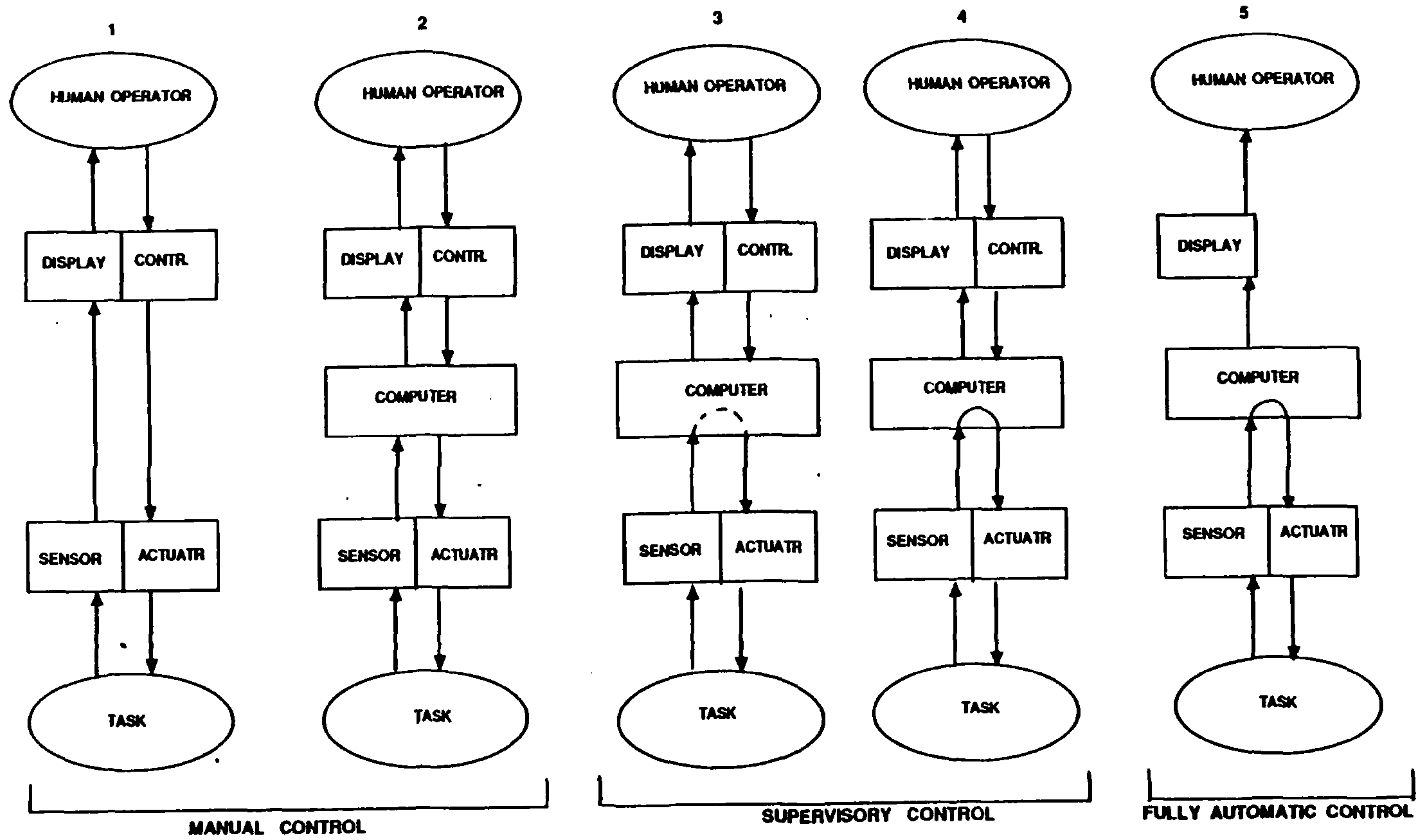



FIGURE 4-1 RELATIONSHIP BETWEEN THREE CONTROL CONCEPTS

receives the commands and makes the necessary adjustments to the vehicle's control surfaces. However, in both of these situations, the operator makes all command decisions. (33,3)

Supervisory control is apparent when some portion of the control is accomplished through the computer directly closing the control loop. The third and fourth systems depicted in Figure 4-1 represent minor and major fractions of control by the on-board computer. When the control system is automatic, the operator can observe, but can not influence the process. This concept is shown in the fifth system depicted in Figure 4-1.

Supervisory control of UMVs did not come about until the availability of automation technology for UMVs. One of the major problems was resolving navigational errors. It took the incorporation of LORAN or Tercom capability and improved flight control systems to allow UMVs to become fully automated. The incorporation of a Global Position System (GPS) capability will provide sufficient navigational accuracy to perform most missions envisioned.

4.1.2 Major Issue in Automation

The first automation capability incorporated into UMVs involved control of the vehicle in flight. The next step in automation improved the navigation capabilities of the system. What remains as a difficult problem is developing procedures to recover the UMVs through a conventional landing. Consider the following two examples.

- NASA Remotely Piloted Research Vehicles (RPRV). By 1975, NASA's RPRV program had proceeded to the point where they were developing methods for horizontal landings of the RPRVs. The procedure involved using a ground controlled approach (GCA) radar vector to direct the pilot to the final landing pattern approach. The F-15 RPRV had a television camera mounted in the cockpit, which gave the operator a limited outside view through the canopy windshield.

The TV camera's 50-mm high magnification lens provided the operator with some cues during the landing, but the lens had such a narrow field of view that the operator lacked the peripheral vision to align with the runway. The vertical field of view was also limited to about $\pm$ 5.5 degrees.

Operators were assisted during the final landing phase by a second ground operator who called out altitudes using a radar altimeter display from the F-15 cockpit. Pilots in T-37 chase aircraft flying in formation with the F-15 RPRV also reported passing through the 300 ft level. These cues combined with the visual presentation on the television monitor made it possible for the operator to land the F-15 RPRV with acceptable accuracy. (34,32-33)

- Teledyne Ryan Compass Cope. Teledyne Ryan developed an automatic landing capability for their Compass Cope candidate. The system used two Singer-Kearfott Talar microwave landing systems. One system was located at the approach end of the runway to provide guidance to 70 feet above ground level (AGL). At 70 feet, the radio altimeter and flight computer provided flare guidance. The second system which was located at the far end of the runway, provided rollout guidance. The operator only needed to apply the brakes. (35,51)

Today, UMVs are fully capable of completing complex missions without any operator intervention. In fact, some UMV supporters are of the opinion that if the UMV mission does not call for precision flying in the terminal area, and if the vehicle does not have a requirement for a real time data link such as a TV camera, then the mission should be conducted by a fully automated UMV. To some, the operator, at least for in-flight control, is no longer required.

## 4.2 Communications

To control a UMV in flight requires a data link that can transfer commands or control instructions from the control station to the UMV flight control system and payload sensors, and transmit vehicle position and flight status data from the vehicle to the operator. If there is a sensor payload with near real-time capability, the data link must also accommodate transmissions of the sensor data to the control station and accept the transmission of the payload commands from the control station to the vehicle.

### 4.2.1 Communication Data Links

The MMI design is heavily dependent upon the communication requirements. The major communications between the UMV and the operator

are largely determined by the mission of the UMV. However, it is possible to classify types of communications according to the purpose of the communication.

- Real-time surveillance, target acquisition, and the manually guided kamikaze missions require a television camera be mounted in the UMV. The data link must incorporate a wide band video. The capability of the system can be defined by the number of frames per second or the number of lines per second transmitted to the control station. The more frames or lines that can be transmitted, the higher the resolution available to the operator.
- Non real time reconnaissance such as the photo missions flown during the Vietnam War do not require the television camera and the communications bandwidth can be significantly reduced.
- Telemetry and data status information such as the fuel state, RPMs, and pitch attitude, require a moderate bandwidth to avoid distortion of the signal.
- The command link can be intermittent and the data link need only be capable of low digital bandwidths.
- The incorporation of a secondary radar in the UMV for navigation purposes, requires a wideband link for good resolution.

One method of UMV navigation which has a direct impact on the link design is to use of the data link as a tracker. Angle information can be obtained from a static split receiver and range information is obtained from a transponder code inserted in the command signal and returned by the telemetry signal. However, in order to accomplish this, several points should be considered. First, the angular accuracy of the system will depend upon the beamwidth of the antennas, and the siting and stability of the receiver antennas at the ground terminal. Obviously, the lower the frequency of operation, the larger the antenna diameter for a given beamwidth and hence the greater the stability problems. Second, range resolution is inversely proportional to the bandwidth, and the command telemetry channel has to be sufficiently wide to transmit a transponder pulse without distortion. Third, such a location system is more difficult to operate with airborne relays, due to the need to

locate the relay accurately and to the inaccuracy of any bearing measurements made from the relay. (36,99)

Target recognition and acquisition capability also has a significant impact on data link design. A relatively narrow field of view and black and white presentations of television or imaging IR systems make recognizing small low contrast targets while moving at sub sonic speeds "on the deck" difficult if not impossible. Color TV or color cueing has shown some promise in targeting, but it adds to the complexity of the wide-band data link. (37,56).

### 4.2.2 Communication Degradation

The communication between the operator and the vehicle must be unambiguous and should involve minimal delay. Nature, actions of friendly forces, and the actions of unfriendly forces, can degrade communications between the operator and the vehicle.

The data link must be able to maintain a line of sight. This can be accomplished in several ways. In the simplest case, the UMV is never out of sight of the operator. The problem comes about when terrain or vegetation blocks the signal. This requires that the control station be airborne or that the communications be routed through an airborne relay. (There is a capability to maintain an optical fiber connection, but this application appears limited.) When a UMV data link is subject to large path losses due to rain, the data bit rate is reduced significantly. This means a reduction in the frame rate, resolution or size of the sensor picture. To overcome this limitation, the UMV should have a frame store capability that can accommodate a digitized TV picture frame from which data can be selected at a reduced rate.

The actions of friendly forces can cause loss of communication between the operator and the vehicle. Typically, the problem is interference in that more than one individual is trying to use the same frequency at the same time. The solution is relatively simple and involves frequency management, i.e. ensuring that no other transmitters will override the signals between the operator and the vehicle. There were indications that poor coordination in frequency management in Vietnam caused the crash of more than one UMV.

The major threat to UMV communication/data links is active jamming by unfriendly forces. It is necessary to incorporate electronic countermeasures (ECM) into the data link design. Such programs as the Control and Data Retrieval System (CDRS) of the 1970's went a long way towards providing a secure data link. The CDRS provided the ground stations, air operators, and the necessary relay equipment to create a highly jam resistant data link necessary for simultaneous control of numerous UMVs in a dense electromagnetic environment. Pre-strike reconnaissance, strike support, and damage assessment in poor weather is only possible with such a data link. (37,55)

It is necessary that the probability of detection of the data link signals be minimized, preferably to the point where detection is impossible, and the data link signals should have a high degree of immunity to ECM. Because the UMV must have a low radar cross section and IR signature, the data link equipment needs to be small, lightweight, and dissipate little electrical energy. (36,99-100)

#### 4.2.3 Secure Data Links

There are three ways to make UMV data links jam resistant, and these methods have a direct impact on the MMI design. First, designers can use narrow beam antennas with low sidelobes. However, these devices must be accurately aligned to the UMV after periods of no communication. The second method involves spread spectrum techniques to reduce the transmitted power density to minimal levels. The third method is to keep communications to a minimum. (36,100)

#### 4.2.4 Communications Summary

In summary, controlling a UMV and its payload require clear communications. Generally, narrowband data links are used to transmit information such as flight status, while wideband data links are used to transmit sensor data such as a video sigzal. The communications between the operator and the vehicle need not be continuous throughout the mission. However, there can be no ambiguity between operator and vehicle when the two do communicate with each other. The communications link must be able to overcome degradation caused by nature, friendly forces, or by unfriendly forces. Secure communications are currently

available, but only at the expense of developing bandwidth reduction or reducing the number of updates. (6,62).

## 4.3 Video

This subsection concerns several laboratory efforts that could result in increased capability for the UMVs. These paragraphs cover stereo television, panoramic lenses, and introduce the problem of time delay. The use of predictor displays to resolve the timing issues is reserved for Paragraph 4.4.

### 4.3.1 Stereo Television

By displaying slightly disparate video images of a scene separately to each eye, three-dimensional viewing systems provide depth cues in addition to those that are available with only two-dimensional viewing. Unfortunately, significant performance advantages with 3-D viewing have only sometimes been realized. There is evidence of a performance advantage with 3-D viewing in remote manipulation tasks, in which the cameras view the remote scene from a stable position. However, there is little information available on other tasks that involve the viewing of moving stimuli.

The incorporation of stereo displays for UMV control requires that two cameras be mounted on the UMV. Little research has been conducted on incorporating two camera systems into a single UMV. In order to get the required separation between the cameras, it is likely that they would have to be mounted on the wings of the UMV. They may either be incorporated into the UMV wing box, or they could be mounted in pods under each wing.

The Naval Oceans Systems Center (NOSC) has conducted numerous experiments involving viewing systems for remotely controlled vehicles. Although the experiments involved with stereo television involved a simple manipulator, many of the findings are applicable to UMVs. In their earliest experiments, NOSC engineers found that performance was better with stereo video than with mono under all conditions tested. They determined after several experiments that performance of perceptually ambiguous tasks was faster and more accurate under stereo viewing conditions, and that stereo provided an even greater advantage when visibility

was degraded. (32,804) In three different experiments, researchers at NOSC determined that disparities provided by stereo TV displays need not be equal to those available under direct viewing conditions for optimal performance. In fact, exaggerating disparities by up to 3 times the normal interocular distance enhanced depth estimation without producing greater fatigue so long as the disparities were not large enough to exceed fusional limits and the display was carefully aligned to eliminate vertical disparities. (32,806)

The possible advantages of using motion parallax cues as an aid to depth perception were assessed in a more recent set of experiments. In the first experiment, lateral head movements in front of a bench-mounted stereo display produced a "pseudo motion parallax" effect that provided the operator with information regarding the relative depths of televised objects. However, there was no change in stereoacuity between head movement and head stationary conditions. A helmet mounted stereo display and a motion tracking system which coupled movements of a remote control camera head to those of the head and upper body of the operator was used in the second experiment. This system provided the operator with true head motion parallax cues to the relative depths of objects in the televised scene. (32,804)

While the results of these studies have been encouraging, there are two major weaknesses in the understanding of these systems. First, there is currently no suitable theoretical model of human spatial vision for direct viewing from which to make accurate predictions regarding the performance of remote viewing systems. Second, the variables that control retinal disparity in stereo TV displays are different from the variables that control retinal disparity in direct viewing conditions. Interocular separation, ocular convergence angle, and distance to a reference object determine retinal disparities in direct viewing conditions. Eight variables affect retinal disparities under stereo TV viewing conditions: interocular separation, ocular convergence angle, eye-to-eye display screen distance, camera-to-reference object distance, camera separation, camera convergence angle, camera field of view, and display screen width. Thus, viewing a scene through

a stereo display introduces a whole new set of factors that affect visual performance. Existing knowledge in this area does not constitute an adequate basis for making informed engineering decisions about features to be incorporated into UMV video systems. (32,804-805)

In a study conducted by ARD Corporation, subjects viewed video-taped scenes in which two flat, rectangular targets appeared. One target was oriented vertically, the other was oriented horizontally. Subjects were asked to judge the extent to which the targets were aligned or offset in depth. The targets were presented at a range of actual offsets. In some conditions, both targets were static, while in others conditions, the horizontal target moved in a plane perpendicular to the cameras. Lighting, size, and linear perspective cues to depth were controlled so that depth judgments had to be made on the basis of retinal disparity. The subjects' accuracy of judging small differences in depth, at three different target-to-camera distances, was determined as two viewing system parameters were manipulated. The separation of the cameras and the convergence of the cameras was varied independently. (38,808)

In another effort, the Department of Electrical and Electronic Engineering at Trent Polytechnic in Nottingham, England developed a three dimensional television system which could be mounted on a remote vehicle (in this case, a ground vehicle). They designed a system that used a time-division technique which took advantage of the interlace facility in the standard television display and employed electro-optic lenses in the viewing spectacles. The camera unit had controlled focus, zoom, and convergence, but a fixed camera separation. The operator could adjust the parameters of the stereo-camera as the working visual range of the robotic vehicle changed. (39,809)

In conclusion, the visual information available in the images from today's standard broadcast camera is far less than that available to a person viewing the scene directly, and is not sufficient to meet the requirements of UMV operators. A second conclusion is that stereo TV, while more complex and costly, produces significant improvements in performance, especially for those tasks which require positioning in the

depth plane and those which involve unfamiliar tasks. While stereo TV systems are not conceptually complex nor difficult to construct, careful attention must be given to ensure that the images are matched in size and alignment. This can be accomplished by selecting matched cameras, lenses, and monitors. Unfortunately, there are few research programs which focus on human-machine issues of UMVs with television cameras. For example, the consequences of various combinations of camera position and magnification on the operator's perception of motion, or on the operator's resistance to eye strain, nausea, and fatigue is not fully understood.

Although there is still considerable work to be done, the trend is readily apparent. Technology will eventually support the development of stereo displays with high resolution color capability which provide a wide binocular field of view and link the movements of remote cameras to operator head movements. (32,806)

4.3.2 Panoramic Television Lenses

Use of lenses with different size fields-of-view results in certain distortions of reality which may degrade or enhance operator performance depending upon the maneuver being performed. Magnifying lenses give good rate information resulting in smoother flares for landings, but the foreshortening and magnification results in distorted height information, motion sensitivity, and the possibility of losing sight of the runway when a crab into the wind is required. (40,4-9)

There are definite perceptual limitations inherent in a narrow field of view system. Depending on the orientation of the line of sight of the video system relative to the vehicle's longitudinal axis, a steep approach may cause the horizon to be lost from view. If the vehicle is pitched up, the runway may not be seen. When close to touchdown with a very narrow field of view, this situation may result in both the horizon and the runway disappearing. Use of a motorized zoom lens is not acceptable because this gives the operator another variable and another control at a critical point in the flight. Even a programmed zoom would introduce a variable at a time when the operator needs a consistent visual field for reference. (41,368-369)

To overcome some of these limitations, experiments involving a panoramic television lens were conducted at the Dryden Research Center. The modular design of the cockpit stations for the UMVs flown at the Dryden Research Center allow for the incorporation of a variety of aircraft information devices. In addition, these stations have a graphic display system, an X-Y plotting system, and various input/output devices. Figure 4-2 shows a typical UMV cockpit at Dryden. Despite the variety of potential information systems in these cockpits, the operators consistently reported difficulty in perceiving position relative to the ground during the last 100 meters to touchdown. Operationally, this is handled by having the flight test engineer, who is always at the UMV operator's side during a test, call out the closing altitude from a radar altimeter. This was necessary because the operator's entire attention was focused on the forward field of view. The operators felt that the workload was unnecessarily high and could be reduced with better video. The problem of height perception was critical and felt to be related to the degradation of depth cues. (41,368)

Flying current UMVs produces a loading effect on the operators which is due in large part to the restrictive nature of the forward field of view. The normal aspect ratio, broadcast quality, monochromatic video system does not provide the normal visual cues present in live flight. Operators have been more dissatisfied with this aspect of the system than with any other. The human vision system uses many more cues that just binocular disparity to establish spatial position. Among these are relative sizes and perspective in both static and dynamic conditions, and also closure rates and streaming in dynamic conditions. A very wide angle video system would seem to answer many of the forward field of view questions. However, interfacing a wide field of view camera into a limited bandwidth system results in very small images across the entire field and poor resolution. This combination of factors led to the use of a non-linear lens system. (41,369)

The Variable Acuity Remote Viewing System (VARVS) was conceived as a technique for resolving the FOV/resolution/bandwidth tradeoffs that exist in remote viewing systems. This system is based on

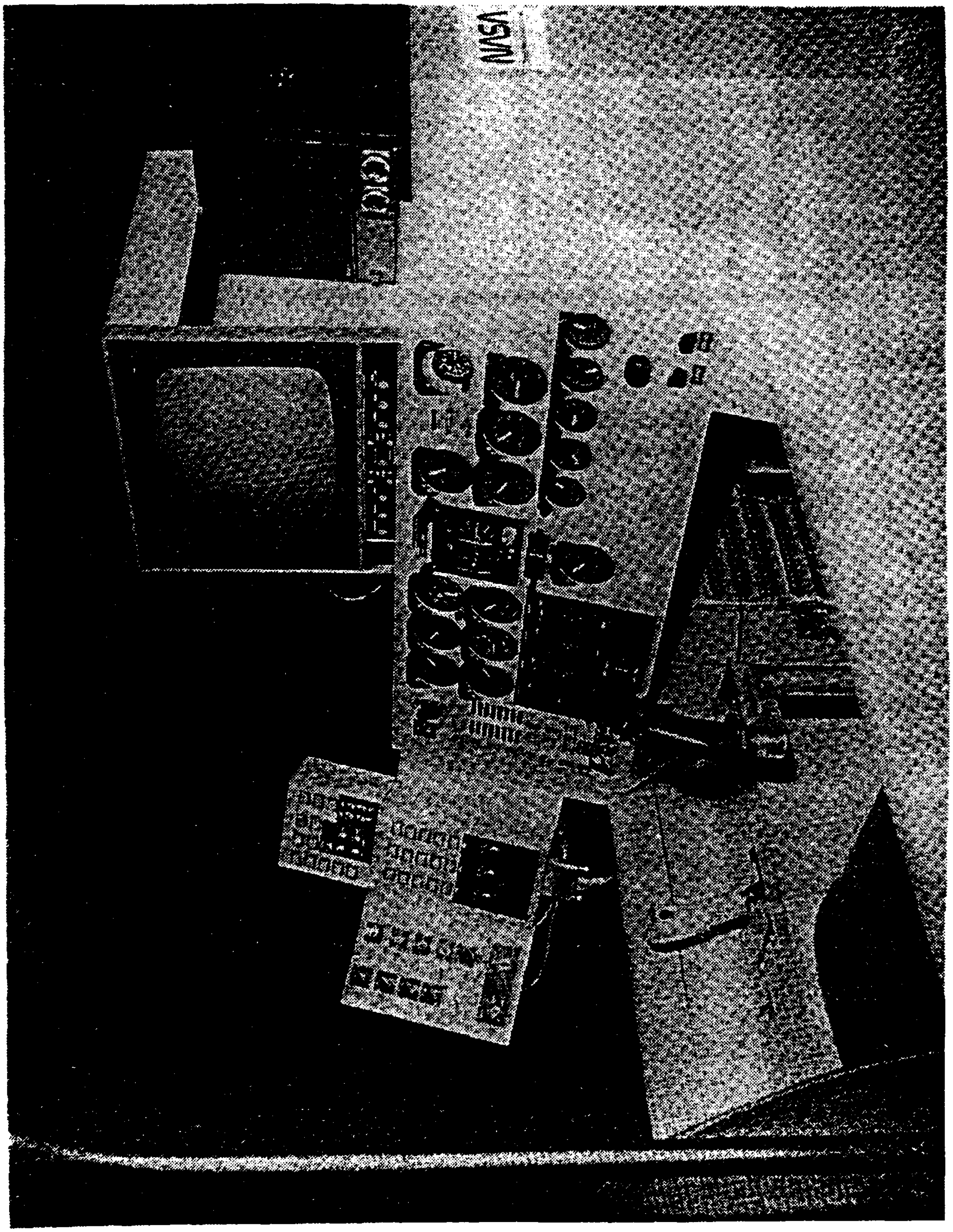


FIGURE 4-2 TYPICAL UMV CONTROL STATION AT DRYDEN

the fact that integration of the human eye acuity function shows only about 130,000 pixels are required to fully support human vision. This quantity is well within the capabilities of conventional video systems. (41,370)

The technique uses a non-linear optical system in both the sensing and display equipment. The non-linearity is achieved by a special lens which translate a uniform pixel array on its image plane into the object field as a variable angular array. This can be contrasted to the "Fish Eye" wide angle lens which projects into the object field with equal angular increments. (See Figure 4-3) In another sense, this lens will record the same angular detail into a uniform matrix of equal sized picture elements on its image plane. The image can be scanned with a broadcast quality TV having a 525 line raster scan. Conventional transmission equipment can then be used to send the image by a light valve projector onto a hemispherical screen through an identical non-linear lens. Figure 4-4 shows the VARVS projection dome with the UMV cockpit in place. This projected image is viewed in apparent high acuity and correct geometric perspective when the observer's eye is aligned with the projector's optical axis. (41,370)

### 4.3.3 Real Time Issues

Due to the speed of light, if the human operator and the UMV are separated by extreme distance, (involving use of airborne or satellite video relay), approximately 1/10 to 1/2 second pure transmission time delay occurs in the control loop. This means the operator faces as much as 1 to 2 seconds delay, between receiving a stimulus, transmitting a change to the UMV, and receiving feedback that the vehicle has responded to the change.

The situation could become even more complex because of the requirements real time display has on the communications link. According to F. David Schnebly, a UMV industry consultant, the requirement for real time display causes such engineering complexities that overall performance may be degraded. One solution is to transmit pictures on a delayed schedule, thus simplifying the air to ground link. According to Schnebly, "If you give up just a little in real time, it can save you a lot." (24,38-43)

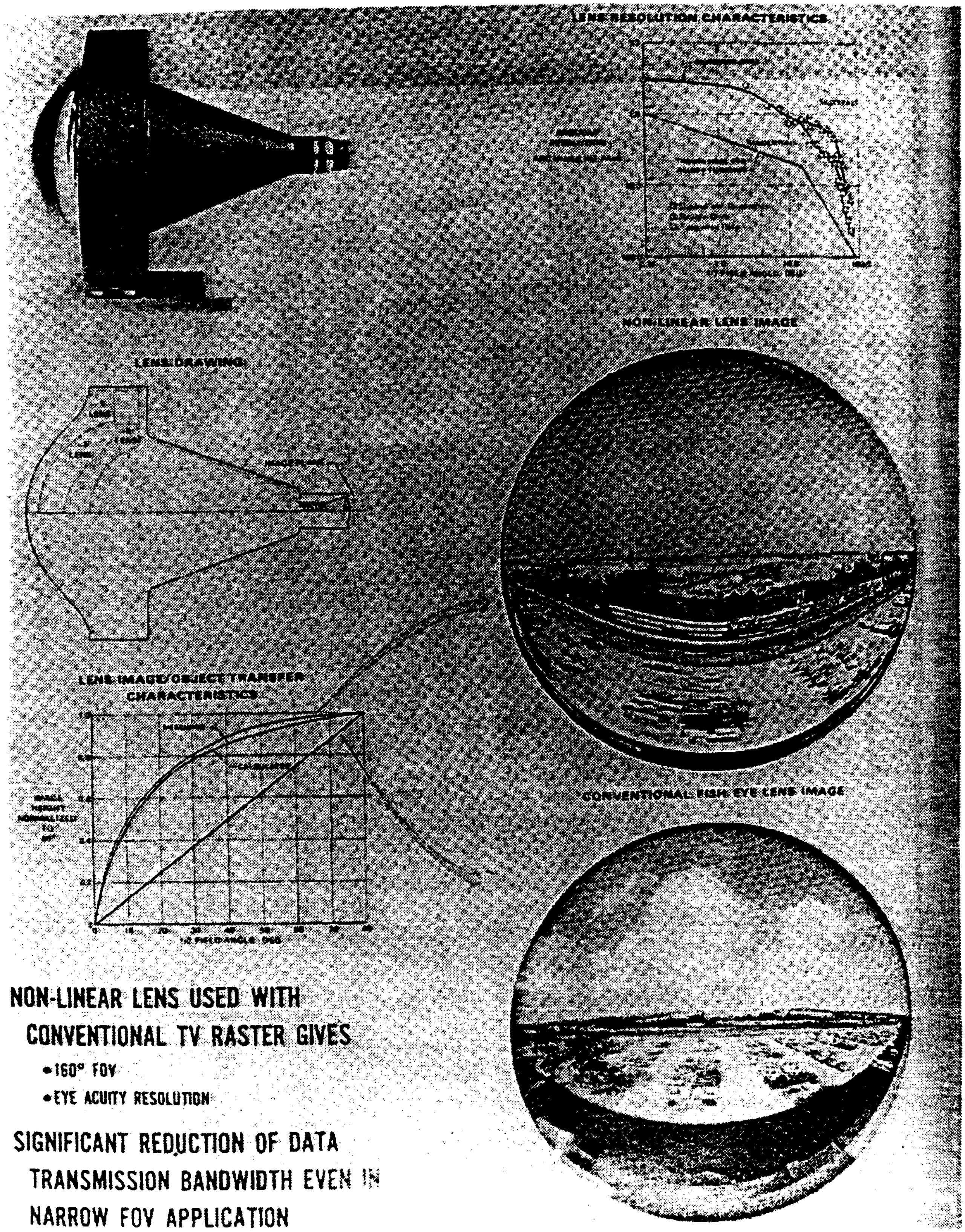



FIGURE 4-3 NON-LINEAR TELEVISION LENS

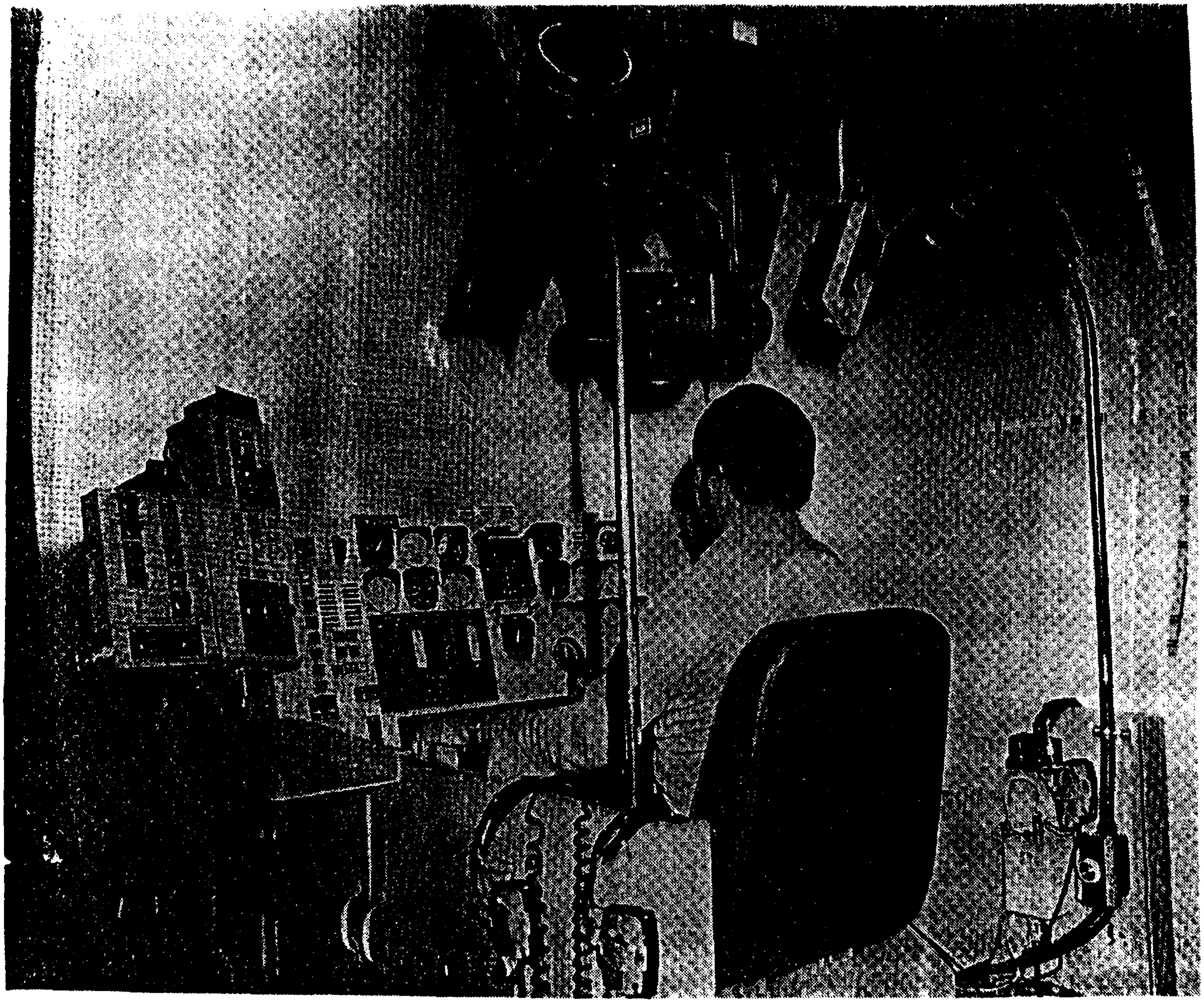


FIGURE 4-4  VARVS INCORPORATED INTO UMV CONCEPT

Psychologists have known for years that if one talked into a tape recorder and listented to one's own voice a fraction of a second to several seconds later, one could not count from 0 to 10 without incurring a complete breakdown. A few recent laboratory experiments in delayed manual tracking of a cursor with a joystick produced irregularities and instability of human response, and the psychological literature records associated with emotional frustration. (42,220)

According to feedback control theory, a pure delay of T seconds in a continuous closed control loop system will result in an unstable (exponentially increasing in amplitude) oscillation of frequency 1/2T hertz, provided the closed loop gain at this frequency exceeds unity. In a 1963 report on an experiment with a "minimal manipulator, Sheridan and Ferrel reported instability, even in performing simple tasks, was controllable only by doing part of the work "open loop", then stopping and awaiting feedback. In another experiment at MIT, researchers determined that performing simple tasks with a 3 second delay took 10 times longer than if there was no delay. These experiments confirmed that transmission delay disproportionately affects the portions of the task normally requiring the greatest precision. (42,220)

The "move and wait" tendency is not the best method for dealing with video time delay. The best approach to avoid the time-delay problem is to use supervisory control, (covered in Paragraph 4.1). The operator provides instructions over the telemetry channel to a computer on-board the UMV. (42,221-222)

## 4.4 Predictive Displays

A predictive display (PD) extrapolates the present position of the UMV by use of a fast-time computer model of the vehicle's dynamics, and graphically presents both the present and future status of the vehicle on a CRT. In effect, the display immediately shows the operator where the UMV will be at some point in the future as a result of each control action. In addition, the model compares the projected location and trajectory against a desired location and trajectory, permitting the operator to know in advance what control actions will be necessary to achieve appropriate guidance. (43,3)

Although relatively little systematic research on PDs has been conducted, a fair amount of literature has been devoted to associated demonstrations, mini-studies, theoretical considerations, and general discussions of potential worth. Despite the lack of empirical studies, what has been accomplished shows that PDs greatly enhance UMV operators in both training and operational modes. Evaluation of previous pilot-controlled simulated aircraft landings accomplished via use of PDs provides reasons to believe PDs may have considerable potential in facilitating UMV recovery tasks. (43,3)

UMV landings require full, remote operation of all aircraft controls to ensure safe, reliable recoveries. The operator is normally stationed just off the runway at the expected touchdown point. Since flight attitude information is not normally available to the recovery operator, estimates of satisfactory landing conditions are made through visual and auditory cues. Because of a lack of visual displays which provide accurate information on the status of the UMV, the recovery operator is required to "eyeball" the task without error. Extensive experience is required, yet UMVs are still lost during the landing phase of the mission.

Use of a PD for facilitating the UMV landing task would appear to have considerable potential, especially during glideslope descent, up to a few seconds before touchdown. A study conducted by Dunlop and Associates in 1976 explored this very topic. Results of the study demonstrated that use of a PD greatly facilitates performance in a simulated UMV landing task. As measured in terms of integrated altitude error, performance was approximately 50% poorer without the display. Moreover, despite the fact that its benefits were substantial in the early trials, performance with the PD steadily improved throughout the remaining trials. (43,6-18)

An additional benefit of PDs is training. As far back as 1958, it was determined that use of PDs for some tasks transformed inexperienced operators into experts in a relatively short time. The reason for this increased learning speed is that the skilled operator spent weeks or months learning the complex dynamic characteristics of

the system so as to be able to know what the UMV would do under varied conditions. The operator using a PD knows from the start what the UMV will do. The instruments tell him, because the UMV dynamic characteristics are built into the PD and in this way displayed to the operator. (43,18-10)

No data was available to indicate that research had been conducted to determine if the performance level resulting from training without a PD eventually converges upon the performance level resulting from training with a PD. The answer to this question has an important bearing on UMV operations. A primary advantage of a PD is its ability to show an operator how the UMV will respond to various control inputs. Theoretically, once an operator has learned the response characteristics of the UMV, the PD may lose some or all of its value. Thus, if experienced operators derive no significant benefit from the PD, then the greatest value of the PD may be as a training aid. On the other hand, if the performance levels do not converge, than PDs would seem to have important applications to both training and operations. Previous work by Dunlop and Associates demonstrated dramatic transfer of training effects from the predictor to a conventional display. (43,19)

The question is not quite this simple. For example, in stressful situations, operators make errors regardless of their experience level. Because information from PDs is so much greater, relevant, and easier to integrate than information from conventional displays, it is likely that stress will have a significantly lesser effect on operators using PDs. (43,19)

The last two or three seconds of a UMV landing involve the easiest perceptual requirements of the task, since the operator's line of sight, relative to the UMV, approaches a line perpendicular to the longitudinal path of the UMV. In addition, direct visual access to the vehicle just prior to and at touchdown provides more accurate information than is possible through the use of any display, including a PD. It has been suggested that the PD would assist the UMV operator until the last two or three seconds prior to touchdown, after which, the operator assumes direct visual control. (43,20)

Despite its potential and the fact that the PD had been in existence since 1958, the quantity and quality of the accumulated research associated with PDs has been relatively unimpressive. There has not been enough research to determine the optimum configuration of the PD. In addition, some of the experiments that have been conducted were more like demonstrations. (43,20)

One of the problems associated with PDs is the need to incorporate an accurate fast-time model of the UMV in order to make the predictions. Since the fidelity of the predictions is dependent upon the fidelity of the fast-time model, the model must reflect realistic operation of the UMV. Unfortunately, no one knows how much realism is sufficient. (43,22)

In summary, the complexity of control over UMVs, at least in landing them, requires highly trained and experienced operators. The consequences of operator error have risen dramatically. It seems clear that attention should be given to reducing the complexity of the task. PD technology might be one method that can lead to significant reductions in operator workload during the recovery of the UMV, and therefore, should be explored.

## 4.5 Training

On one side of the UMV MMI is the equipment. On the other side of the MMI is a human operator. The relationship between the operator and the MMI from the human perspective is a difficult issue to address and rarely is discussed in the literature. It is considerably easier to discuss the merits of different equipment designs.

### 4.5.1 Importance of Operator's Background

The issue that draws the most heated debate is what type of individual makes the best operator - pilots, weapon system officers (WSO), air traffic controllers (ATC), people with no flight experience, but with knowledge of the principles of flight, or those that must be taught everything. There are many sides to this argument and many times, each point of view has a valid claim that is dependent upon the different missions UMVs can perform. A subset of people involved in UMV research and development firmly believe that pilots with full size

aircraft experience are rarely the best operators, and are extremely difficult to train. That is why the issue is rarely addressed in the literature. The UMV supporters have spent the last two decades arguing that UMVs are complements to manned aircraft not competitors. However, many rated personnel still feel threatened by UMVs. There is no need to compound the problems of UMV supporters by telling the non supporters their skills hamper their ability to learn to control UMVs, and that non-rated individuals can fly UMVs better than them.

In controlling a vehicle visually, there is usually little more than a small control box consisting of a joy stick or control knobs and a few push buttons. Flight instrumentation is extremely limited. The operator is restricted to visual cues for determining flight status or attitude. Whether the vehicle is climbing, in a bank, or falling out of a turn must be determined visually by the operator. The operator has to transpose his sense of direction and stability to an aircraft he is trying to fly visually, perhaps 4 miles away. The operator's references such as the horizon are steady, but the aircraft is constantly changing. Normally, pilots receive their visual cues from inside the aircraft. When the aircraft nose is down, the ground is out the front window. The preceding example may seem silly, but it gets to the crux of the issue. The pilot is trained to relate to a fixed frame of reference relative to the aircraft and a constantly changing frame of reference to the outside world. The UMV operator is trained to relate to a fixed frame of reference relative to the outside world, and a constantly changing frame of reference relative to the aircraft.

Shorts Brothers, a UMV manufacturer in Ireland, determined that the most difficult person to train was a pilot with full size aircraft experience. The pilot would have to be retrained to fly without the "seat-of-the-pants" instincts that he was taught to rely on. Pilots of radio-controlled model airplanes, with a disciplined approach to flying the larger UMVs, often possessed sufficient skills to maintain the aircraft with very little instruction. (44)

Controlling UMVs beyond visual range is even more difficult to adjust to. The operator must remain at a console. A pilot might be

at home with several of the current control stations. Many of the flight instruments available to the pilot in the cockpit are available to the operator on the ground. Several of these designs even have rudder petals. While it is true that flying a UMV from these control stations is not much different than flying strictly by instruments in an aircraft, the operator does not feel the motions the pilot does. The operator also is forced to deal with a two dimension display to determine the location of the vehicle in 3 dimensional space. These displays can be an X-Y plotter, or they may have some sort of a CRT type display. WSOs, EWOs, and ATCs are all experienced in visualizing a three dimensional image on the basis of two dimensional data, and they have little trouble in transitioning to reading the UMV displays.

Whichever group you talk to relative to who makes the best operator, there is one thing they will all agree on. The most important attribute for a good operator is that the operator fully understands the vehicle. They must know how the flight control system works, how the vehicle responds to commands, how long it takes for the vehicle to react, and the limits of the vehicle's operating envelope. Without this knowledge, the operator is unable to visualize the position and attitude of the vehicle, and this can lead to disaster if the vehicle is under manual control. Flying a UMV at several hundred miles an hour at 100 feet altitude using controls and a television monitor operating on a half second or more delay is a skill that takes practice and patience to learn.

Individuals at Northrop Ventura discussed an issue that arose with training some foreign nationals on how to fly their target drones. Apparently, there was little difficulty in teaching the new operators to fly under visual conditions. Learning to use the plotter was entirely different. It seems the foreign nationals had great difficulty controlling the vehicle when they were dependent upon the plotter for determining vehicle position. This led Northrop to develop the capability to train operators with real control stations, but using simulated UMVs.

### 4.5.2 Human Factors and Control Stations

Very little effort has been expended on designing control stations from a human factors point of view. The design of these stations

usually has had lower priority, with the higher priority going towards ensuring the air vehicle is capable of performing to the requirements. There are a host of opportunities available to those who will expend the resources to adequately ensure a design is compatible to the operator. For many of the mobile ground stations, the operator(s) sits in cramped quarters, and faces racks of equipment that have been squeezed into the back of a truck. Space is at a premium. Evaluation of the locations of individual displays, switches, and buttons of the various control station designs reviewed was outside the scope of this effort, but it is definitely an area to be explored in future UMVs.

Another issue faced by the designers of control stations for complex UMVs is the relationship between the sensor operator and the vehicle operator. Lockheed had problems with their Aquila design in working out the training for the relationships between the three operators, their equipment, and their use of highly automated systems. Integrating the work of three soldiers in the ground control station doing different things with their computers independently also created problem. In addition, the system had to be made to accommodate the mistakes of human beings, such as an operator pressing a button twice by mistake or pushing the wrong sequence of buttons. (45,88-89)

### 4.5.3 Importance of Training

There is no clear consensus on the best methods for training and there are no standards for determining how much training is required for proficiency. Very little data is available, but it appears that a lot of training is required to overcome the problems faced by inexperienced operators. The mishap data reports for UMVs have numerous references to vehicles lost due to operator error where that error would not have occurred if the operator had additional training or was more knowledgeable about procedures.

Flying UMVs can be stressful. There are reports of trainees breaking out in sweat while controlling simulated UMVs, let alone the real thing. Additional research is being conducted on the stress exerted on operators. According to Kenneth Bosonworth, president of International Resource Development, many operators react to scenes on

the control monitors as if they were piloting a vehicle in the air and were looking out the window. Training appears to reduce the severity of this problem. (24,38-43)

According to the literature, there does not appear to be a problem with controlling UMVs that can not be avoided with training. Control stations can be linked into computers which can simulate the UMV. Training can take place at any time, under any condition, and there does not have to be a vehicle in the air. Obviously, tasks like manually landing one of the larger UMVs requires a lot of training with the vehicle, but many other tasks are well suited for simulation. There was no data to indicate that some classes of people could never be trained to fly a UMV. The question remains as to how much training is required for minimal proficiency, and how much additional training various control station designs require because they reflect a poor human factors design. This study was unable to answer that question, but it could be explored in greater detail in the future. Obviously, one goal of any future UMV program would be to design a control station that does not add to the training burden because of poor human factors engineering.

## 5.0 CONCLUSIONS

The evolving nature of the MMI for control of UMVs is a paradox. On the one hand system designers now have a tremendous opportunity to design new systems from the ground up to fit the operator and the mission, unimpeded by past restrictions that have traditionally inhibited manned aircraft designers. On the other hand, system designers face a bewildering variety of interdependent and largely unresolved criteria that fundamentally affect every facet of system configuration. There is a need for firm answers to a series of basic, but highly related questions:

What is the nature of the specific UMV design in terms of mission? The UMV can be a multi-mission or a specialized vehicle. Is the vehicle to be recovered or is it expendable? What are the primary navigation or guidance capabilities?

If the vehicle has multi-mission capabilites, what types of missions are considered compatible in terms of on-board avionics and control capabilites, resistance to countermeasures and jamming, and terminal guidance accuracy?

To what extent are on-board avionics systems programmed or dependent on ground commands? Is enroute navigation conducted as a self contained on-board function with provisions for ground updating, or must a ground control station determine the UMV's position with a consequent increase in vulnerability to countermeasures?

Are wide-band data links and frequent guidance signals required, and what techniques must then be employed to afford maximum protection from detection, jamming, and deceptions?

Does a man have to "fly" the UMV continuously, or does the controller simply supervise a system with the self contained capability to arrive at the target area? Should the man-in-the-loop be a rated pilot, a weapons system operator or even an experienced radar traffic controller, at least for the enroute portion of the operation? How many UMVs can one controller successfully control during enroute phases of flight? How much active data must the controller receive back from the UMV, and in what form to assure proper operation and control? Is it

necessary or desirable to hand off control of each UMV to a specialist in reconnaissance, strike, or other mission as it nears its target area?

Display philosophy is derived from, and closely related to, the control philosophy. A system that requires exchange of information between the UMV and the controller requires a wideband link to handle video, infrared or radar information, while command and control functions can be handled with a narrow band link. The narrow-band data link is easier to protect from jamming, mutipath effects, and other interference. However, as a high level of anti-jamming techniques, such as pseudo random noise, frequency hopping and spread spectrum techniques are employed, the cost of the data link goes up dramatically. Eventually there needs to be a tradeoff between system cost and protection capability.

Up until the middle of the 1970s, the major MMI issues concerned how much information was required by the controller, the format for that information, and how often the information should be presented. However, MMI issues have proliferated. Now, not only are information requirements important, but their impact on workload, automation, and supervisory control must be considered.

We have therefore prioritized the MMI issues that require further research. The objective is to provide a coherent structure that can be used to best organize future Air Force research programs in the MMI area. We have considered both technical and mission trends in the ratings, although without the inclusion of classified data there may have been aspects that were not properly addressed. However, the organization provides a useful first analysis regardless of any missing factors.

The major issues facing researchers are those that are being addressed in Section 4. These are automation, communication, video, predictive displays, and training. Additional areas that we feel need further research from Sections 2 and 3 are workload assessment and supervisory control. These areas are interrelated and require an overall systems approach to their solution. Such an approach is System Analysis, a top-down systematic decomposition process. Although System Analysis is

commonly used in hardware development, the concept still has not taken hold in the engineering community for its use in the Personnel Subsystem development. This is in spite of the fact that Air Force development efforts should include personnel consideration.

Within the Personnel Subsystem, both operators and maintainers should be considered. While the results of our review and analysis have demonstrated the role of the operator or operators, the maintainer has not been explicitly mentioned. Yet, like all emerging systems, maintenance is just as important as operations when overall mission readiness is considered.

Much of what has been described is not specific to UMVs. Rather UMVs are a microcosm of the problems the Air Force faces with personnel, human factors engineering, and training issues in new systems. What is specific to the MMI of the UMV is the priority of research issues.

The research issues in terms of priority for further analysis are:

- workload assessment
- automation
- supervisory control
- training
- video
- predictive displays
- communication

The sequence is primarily based on the increasing demands crew personnel will face in new generation UMVs. Such demands will require a detailed workload assessment that, in turn, will require careful reassessment of the role of automation and supervisory control concepts. These items are closely followed by training considerations to ensure that all personnel, both operators and maintainers, have the knowledge and skills required to do their job. Other issues are rated lower because there is already an experience base and some, however incomplete, research data. Where necessary, educated extrapolations of existing data can be used. However, additional research will be needed in the lower priority areas.

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